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BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

INCLUDING THE

PROGRAMME OF THE

1960 SUMMER MEETING IN THE EAST

AT

MONTREAL, CANADA

June 15–17, 1960

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June 15, 1960 Series II, Vol. 5, No. 5

BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

1960 Summer Meeting in the East, McGill University, Montreal, June 15–17, 1960

CROSSING the border is generally fun, and our crossings of the border have invariably led to happy meetings in friendly universities, but never yet to such a great one as this third meeting of ours in Montreal is going to be. As heretofore in the Canadian metropolis, our host is McGill University. As so often happens when we return after years to a familiar campus, the campus is still familiar and yet the older buildings are interspersed with newer ones; were this not the case at McGill, we should be holding most of our sessions in the hotel.

Leaving the official hotel, one turns right and walks north along Peel Street a couple of blocks to Sherbrooke Street, and there turns right again (eastward); after a few steps no guidance will be needed, for one sees the University spread out along the north side of Sherbrooke Street. Moyse Hall, where some of our biggest sessions will be held, is in the center behind the deep lawn. The McConnell Engineering Building, the MacDonald Chemistry Laboratory, and the MacDonald Physics Laboratory are all at the southeast angle of the campus: I mention the last-named even though we shall be holding no sessions in it, for we have always met in it before. It is full of memories of many physicists, and among these Rutherford, who performed some of his greatest work within its walls. Newcomers should not fail to enter it.

The Chairman of our Local Committee is E. J. Stansbury. In the course of the meeting it will become apparent how much we shall owe to him and his aides.

The **headquarters hotel** is the Sheraton-Mount Royal, in Peel Street slightly north of St. Catherine Street. It has been said and reiterated, in previous issues of this Bulletin and in special communications to members of the Divisions particularly concerned, that deadline for receipt of reservations at this hotel is June 4. Whether this final admonition will reach our membership in time to do any good remains to be seen. If you have not yet written and there is still time to write, mention in your letter that you are coming to our meeting. Some of our members will be housed at the Laurentian Hotel, but all reservations must be made through the Sheraton-Mount Royal.

The **registration desk** will be on the ground floor of the McConnell Engineering Building. Here will be the tickets for the banquet and for other delightful activities, and here will be blackboards for announcement of post-deadline papers, of changes in time or place of sessions if any, and for messages.

The **registration fee** will be one dollar and a half in Canadian currency or one dollar and a half in USA currency, whichever the registrant proffers. In general, any payments at the desk may be made in either currency at par with the other, but this will not be true in Montreal generally, and, unless at the time of the meeting the exchange rate is much closer to unity than at the time of this writing, it will be a convenience to have Canadian currency purchased either before entering Canada or immediately after reaching Montreal.

Invited papers of our **Division of Electron Physics,** which as usual makes this its principal meeting of the year, number eight, and are distributed four and four between two sessions on Thursday.

Invited papers bespoken by joint action of our **Division of Fluid Dynamics** and our newborn **Division of Plasma Physics** are also eight in number and are distributed four by four in two sessions, the one on Wednesday afternoon and the other on Friday morning. This is the first official participation of these two Divisions in our June meeting in the East: we hope it will not be the last.

Invited papers on the general programme are mostly but not wholly from Canadian institutions near to our meeting place: McGill University, the Université de Montréal, Chalk River Laboratories, and the National Research Council of Canada:

Université Laval participates in the programme of the Division of Electron Physics and University of Toronto in that of the two other Divisions.

Two hundred and sixty-four contributed papers are distributed among twenty-four sessions. This is a rise of *one hundred and fifty percent* over the greatest number ever offered to any previous Summer Meeting in the East—a population explosion without precedent in the history of the Society, unless a precedent be found in the very early years when the numbers were small. This makes the Secretary feel like a guest at a cocktail party whose host has graciously granted him permission to bring along a couple of friends, and who then turns up with a couple of dozen. Of this great gain in size a part, I am happy to say, is due to the popularity of our meeting with Canadian physicists, and another part certainly to the attractiveness of McGill and Montreal as the scene of the meeting. The third cause is conspicuous in the pages of this Bulletin. Take note that there is a lengthy session of ten-minute papers in plasma physics on every one of the six half-days of this meeting!

One consequence of this phenomenon is that the distribution of speakers in geography will be considerably different from what is normal for a June meeting in the East—the proportion coming from the Far West will be abnormally high (some of them may be surprised to find how green and lovely the East can be in June). Another and serious consequence is that it will be absolutely impossible to avoid simultaneities between papers of similar interest. Some of the plasma physicists will probably want to hear the invited papers arranged by their Division and the Division of Fluid Dynamics, the ten-minute papers in fluid dynamics, the papers both invited and contributed in electron physics—but not one of all of these can be spared from competition with one or another of the plasma sessions. The simultaneities would undoubtedly be much worse than they are had not John Dawson come from Princeton to this office to spend several hours rearranging the papers so as to minimize them, and he deserves much thanks.

Vu-graphs will be available in the various halls, and we hope that speakers will prefer them to the blackboards, particularly in Moyse Hall where the blackboard must perforce be small, and also in Physical Sciences Auditorium where the blackboard is ample but the hall is deep.

Smoking is prohibited in the lecture rooms of McGill University. Many of our members have been quite lax in this regard, taking it for granted that a "No-Smoking" sign in a University lecture hall is meant to apply only to students in regular classes. This may be true in some places, but it is not true at McGill. Depart into the corridor before you light your cigarette, and stay there until it is quenched.

The **banquet of the Society** will be held on Thursday evening in the Sheraton-Mount Royal Hotel. The after-dinner speaker will be J. S. Foster of McGill University. Contrary to our custom, evening dress is not recommended on this occasion, since the weather may be warm. Tickets will be sold at the registration desk; *they must be bought before five o'clock on Wednesday evening*—if you will not arrive before Thursday, write to Professor E. J. Stansbury, McGill University, Montreal, Canada, and ask him to include places for you in the guarantee that must be made to the hotel. The price of a ticket will be four dollars, Canadian or USA currency.

The University will be host at a garden party on Wednesday afternoon, weather permitting. In case of inclement weather an announcement of plans will be made on the blackboard at the registration desk.

Enviable entertainment for the ladies is being prepared by Mrs. G. A. Woonton with the assistance of Mesdames R. E. Bell, J. S. Foster, P. A. Lorrain, J. S. Marshall, and E. R. Pounder. Those wishing to take advantage of this (and who will not?) are asked to register as early as possible at a special desk which will be set up near the general registration desk in the lobby of the McConnell Engineering Building. The activities include:

(a) a tour of the McGill campus, starting at 2 p.m. on Wednesday afternoon;

(b) a bus tour of the Laurentians, with buffet luncheon at the Chantecler. This begins at 10 a.m. on Thursday and will be ended not later than 4:30 p.m. The all-inclusive price is $7.50.

(c) a sightseeing tour of Montreal with luncheon at the Université de Montréal. This begins at 10 a.m. on Friday. The all-inclusive price is $3.50.

All of these tours start from the lobby of the McConnell Building.

Post-deadline papers, pertaining to very recent achievements of very special importance, will be considered for admission to a special supplementary programme if the abstracts are received *not later than Friday, June tenth*, at the office of Professor E. J. Stansbury, McGill University, Montreal, Canada. We have discontinued the former policy of asking that the abstracts be sent to the office of the Society, for this involved them in two journeys. The titles of such as are accepted will be displayed on a blackboard near the registration desk, and the papers will be given under the usual ten-minute rule at the end of Session WA—some of them perhaps elsewhere if there are suitable vacancies for them.

There being in 1960 no Summer Meeting in the West, this is the last issue of the Bulletin that will appear before November. A preliminary announcement of the 1960 Thanksgiving meeting at Chicago will be found on page 391, and there will be a preliminary announcement of the 1960 Winter Meeting at Berkeley if the Local Secretary for the Pacific Coast wishes to communicate one. There are also announcements of the 1960 Gaseous Electronics Conference and of two Divisional meetings scheduled for the autumn. The calendar of meetings and deadlines to the end of 1961 is printed on page 395. The Local Secretary for the Pacific Coast, W. A. Nierenberg, will be away for some time from the first of July, and his duties to the Society will be performed by E. L. Hahn of the same address (University of California, Berkeley 4, California) who will have the title Deputy Secretary for the Pacific Coast.

The **rules and instructions for the preparation of abstracts** are printed on page 396. They are becoming longer and more detailed, and some of our members have already had occasion to notice that they are being enforced with increasing rigor. A new request is made, viz., that anyone whose name is to appear on the by-line of two or more abstracts make sure that it is typed in exactly the same form on both or all.

Errata pertaining to the contents of this issue will be published in the November Bulletin if received not later than Monday, June 20, by Miss Ruth Bryans, American Institute of Physics, 335 East 45th Street, New York 17, New York. Do not send in your abstract marked with corrections! Write out your corrections in the form "instead of . . . read . . . ." Alternatively you may say "The sentence beginning with the words . . . is to be rewritten as follows . . . ." Add nothing.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

EPITOME OF THE 1960 MONTREAL MEETING

(Personal names are those of invited speakers. DEP, DFD, and DPP stand for Divisions of Electron Physics, Fluid Dynamics, and Plasma Physics, respectively.)

Wednesday Morning

A. Nuclear Physics I: radioactive nuclei. Chemistry Amphitheatre.

B. Atomic theory. Moyse Hall.

C. Plasma I. Engineering 304.

CA. Gold, Barr, Brockhouse, Henshaw. Physical Sciences Auditorium.

D. Woonton; magnetic resonance I. Engineering 204.

Wednesday Afternoon

E. Magnetic resonance II. Engineering 204.

F. Nuclear physics II: nuclear reactions. Chemistry Amphitheatre.

G. Electron emission. Moyse Hall.

GA. DFD and DPP: Kovasznay, Schwarzschild, Roberts, Karr. Physical Sciences Auditorium.

H. Plasma II. Engineering 304.

Thursday Morning

J. Plasma III. Engineering 304.

JA. Seth, Demos, Gottfried, Stewart. Physical Sciences Auditorium.

K. Apparatus of nuclear physics. Chemistry Amphitheatre.

L. Magnetism and cryogenics. Engineering 204.

M. DEP: Auer, Kerwin, Spicer, Spruch. Moyse Hall.

Thursday Afternoon

N. DEP: Herzberg, Marton, Ramsey, Germer. Moyse Hall.

P. Marshall, Pounder; sea ice; optical and x-ray spectra. Physical Sciences Auditorium.

Q. Cosmic rays and space physics; Demers. Chemistry Amphitheatre.

QA. Fluid dynamics I: shock waves. Engineering 204.

R. Plasma IV. Engineering 304.

Thursday Evening at 7:00

Banquet of The American Physical Society; Foster. Sheraton-Mount Royal.

Friday Morning

S. Plasma V. Engineering 304.

SA. DFD and DPP: Lauer, Hooke, Patterson, Nagamatsu. Moyse Hall.

T. Nuclear physics III. Chemistry Amphitheatre.

U. Discharges in gases. Physical Sciences Auditorium.

V. Solid-state physics I. Engineering 204.

Friday Afternoon

W. Solid-state physics II. Moyse Hall.

WA. Fluid dynamics II: post-deadline papers, if any. Physical Sciences Auditorium.

X. Nuclear and general theory. Chemistry Amphitheatre.

Y. Molecular and general physics. Engineering 204.

Z. Plasma VI. Engineering 304.

PROGRAMME

WEDNESDAY MORNING AT 10:30

Chemistry Amphitheatre

(J. S. FOSTER presiding)

Radioactive Nuclei

A1. Electron-Capture Decay of Ge^{68}.* M. K. RAMASWAMY,† *The Johns Hopkins University* (introduced by P. S. Jastram).—270-day Ge^{68} decays by 100% electron capture to 68-min Ga^{68} which in turn decays by positron emission (~87%) and electron capture to stable Zn^{68}. By use of scintillation techniques, the K x rays emitted by Ge^{68} have been compared with the amount of annihilation radiation present in the Ga^{68} source when in equilibrium with Ge^{68}. This leads to an L to K electron-capture ratio of 0.12 ± 0.07 in agreement with the theoretical value and consistent with a recently measured[1] value of 0.09 ± 0.05 Ge^{71} in decay.

* Work supported in part by the U. S. Atomic Energy Commission.
† Present address: Department of Physics, The Ohio State University.
[1] D. E. Rehfuss and B. Crasemann, Phys. Rev. **114**, 1609 (1959).

A2. Decay of Br^{78}.* R. RIKMENSPOEL AND D. M. VAN PATTER, *Bartol Research Foundation*.—The decay scheme of $Br^{78}(\beta^+)Se^{78}$ has not yet been established with certainty.[1,2] Br^{78} sources were produced by proton bombardment of isotopically enriched (97%) thin targets of Se^{78}. The (p,n) threshold for the $Se^{78}(p,n)Br^{78}$ reaction was measured at 4.35 ± 0.01 Mev with a slow-fast neutron counter arrangement. The proton energy was calibrated with the $F^{19}(p,n)$ threshold at 4.24 Mev. Annihilation radiation with a half-life of 6.4 ± 0.2 min was observed for bombardments with $E_p>4.35$ Mev. After bombardment with 4.35 Mev $\leq E_p<4.48$, the β^+ decay showed no evidence of the growth of a daughter state from an isomeric level. By using an anthracene crystal, the end point of the β^+ spectrum of Br^{78} was measured at 2.52 Mev in essential agreement with the Q of the (p,n) reaction of -4.30 Mev. The energy was calibrated by means of the β^+ spectra of Ga^{68}, Zn^{63}, and Cu^{62}. A gamma ray of 0.615 Mev was observed in the decay of Br^{78}, which is assigned to the first 2+ level of Se^{78} on the basis of its half-life of approximately 6.5 min.

* Supported by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command.
[1] D. Strominger *et al.*, Revs. Modern Phys. **30**, 649 (1958).
[2] W. R. Pierson and C. P. Coryell, MIT LNS Rept. (February, 1958).

A3. Half-Lives of First Excited States of Heavy Even-Even Nuclei. R. E. BELL, S. BJØRNHOLM, AND J. C. SEVERIENS, *McGill University and University of Copenhagen*.—The half-lives of the first excited states of eighteen even-even nuclei of Em, Ra, Th, U, and Pu have been measured by the delayed coincidence method, using a fast time-to-amplitude converter. The experimental half-lives were all found to lie between 1.5 and 7.6×10^{-10} sec. The results are used to calculate reduced transition probabilities, quadrupole moments, and deformation parameters for the nuclei concerned. Comparisons are made between these values and recent theoretical calculations. Agreement within 10% or less is found. As by-products of the present work, upper limits have been set for the half-lives of two excited states in Th^{230} and U^{233}, and the calculated $E2$ conversion coefficients of Rose have been verified within about 15% for this region of Z and energy.

A4. Properties of Neutron Deficient Isotopes of Xenon. R. B. MOORE, *McGill University* (introduced by J. S. Foster).—Radioactive xenon produced in LiI by proton bombardment from 30 to 85 Mev in the McGill cyclotron is used to prepare suitable spot and line sources in a modified Lo Surdo tube. Observed activities show half-lives of 17 ± 1 hr (γ: 0.05473, 0.07456, 0.11312, 0.18758, 0.24245 Mev) assigned to Xe^{125}; 1.85 ± 0.03 hr (γ: 0.14857, 0.17759, 0.32855 Mev, positron spectrum of end-point energy 1.505 ± 0.015 Mev) assigned to Xe^{123}; 18.5 ± 0.5 hr (γ: 0.9028, 0.14815, 0.2389 Mev; positron spectrum of end-point energy 3.12 ± 0.04 Mev) assigned to Xe^{122}; 40 ± 2 min (γ: 0.08000, 0.09551, 0.13250, 0.437-Mev positron spectrum of end-point energy 2.77 ± 0.10 Mev) assigned to Xe^{121}; 60 sec (γ: 0.075, 0.111) assigned to Xe^{125m}. Simple decay schemes are presented. An inversion in level order in Xe^{125m} is evidence of a negative nuclear quadrupole deformation.

A5. New Isomers in Polonium. C. K. HARGROVE AND W. M. MARTIN, *McGill University*.—Gamma rays from isomeric states produced by bombarding heavy targets in the extracted beam of the McGill cyclotron have been studied. A single 1.5-in.×1-in. NaI(Tl) crystal measures the γ rays between cyclotron pulses. Radioactive decay is observed using a time sorter based on magnetron beam switching tubes, and the energy spectrum is analyzed with a 256-channel kicksorter. The measurable half-lives are from 20 μsec to 10 sec. Selective absorption of associated K x rays together with reaction yield curves indicate the isomeric nucleus. An isomeric transition ($T_{\frac{1}{2}}=3$ sec) has been found in Po with an 810-kev (M4) γ ray and a 284-kev (M1) γ ray. Another isomeric transition in Po^{207} ($T_{\frac{1}{2}}=45$ μsec) has an 810-kev γ ray and a 310-kev γ ray tentatively assigned as E3 and M1, respectively. A further 160-kev γ ray has been found in the Po^{205m} isomer ($T_{\frac{1}{2}}=644$ μsec) to go with the 707-kev γ ray previously observed.[1] Gamma rays arising from the bombardment of lead are being studied.

[1] W. T. Link, Ph.D. Thesis, Radiation Laboratory, McGill University.

A6. Properties of Ground State ($K=\frac{1}{2}$) Rotational Band in Pu^{239}. G. T. EWAN, R. L. GRAHAM, AND J. S. GEIGER, *Chalk River Laboratories*.—The conversion line spectrum of the 7.85-kev transition in Pu^{239} between the first excited state ($\frac{3}{2}+$) and the ground state ($\frac{1}{2}+$) has been studied in the Chalk River $\pi\sqrt{2}$ β-ray spectrometer. The N, O, and P subshell lines have been resolved. The $N_1:N_2:N_3$ subshell conversion line ratio is found to be $1.0\pm0.12:0.72\pm0.10:0.69\pm0.10$. From these ratios we deduce that the M1/E2 quantum mixing ratio is ~300. This ratio, combined with the results on other transitions within the $K=\frac{1}{2}$ band reported earlier,[1] makes it possible to solve for most of the parameters used in describing a $K=\frac{1}{2}$ band on the Unified Model. Two sets of solutions are obtained for $|(g_s-g_R)|$ and b_0, i.e., for the difference in the intrinsic and rotational gyromagnetic factors, and for the "decoupling" parameter occurring in the M1 transition probability. One solution is in qualitative agreement with the predictions of the Nilsson model; from this set of parameters one predicts a small ground state magnetic moment in agreement with the recent measured value of $\mu=\pm0.02$ n.m.[2]

[1] Ewan *et al.*, Phys. Rev. **116**, 950 (1959).
[2] Hubbs *et al.*, Phys. Rev. **109**, 390 (1958).

WEDNESDAY MORNING AT 10:15

Moyse Hall

(P. R. WALLACE presiding)

Atomic Theory

B1. Photodetachment of H^-. S. GELTMAN AND M. KRAUSS, *National Bureau of Standards.*—By using successively improved bound state wave functions and a plane wave continuum function, Chandrasekhar *et al.* have calculated absorption coefficient curves that are in good agreement with experiment. However, the recent experimental results of Smith and Burch[1] reveal small but significant differences between the calculated and theoretical shapes, most pronounced at wavelengths greater than 8000 A. The use of Hartree and Hartree-Fock[2] continuum functions does not sufficiently improve the agreement with experiment and points to the necessity of investigating the effects of more accurate continuum functions. Results will be presented for a calculation using a 5-parameter continuum function obtained from a variational scattering calculation and the Hart and Herzberg bound state function.

[1] S. J. Smith and D. S. Burch, Phys. Rev. 116, 1125 (1959).
[2] T. L. John (unpublished).

B2. Interaction of Two Helium Atoms. J. S. DOOLING AND P. PIPER, *Catholic University of America.*—Calculations using the LCAO MO SCF approximation were carried out for the ground state of two He atoms for distances ranging from 2.51 A to 3.76 A. The atomic functions used as the basis set were Slater orbitals with $\zeta=1.6875$ on all atomic orbitals. In the first calculation the MO's were constructed from $1s$ and $2p\sigma$ on each atom; the second calculation used as the basis set, $1s$, $2s$, and $2p\sigma$ atomic orbitals. Curves for the interaction potential for each of these calculations show a minimum in the van der Waals' region. The inclusion of the $2s$ atomic functions in the basis set lowers the minimum and shifts it toward smaller internuclear distances. The degree to which the wave functions lead to the fulfillment of the virial theorem was tested, and the results will be shown.

B3. Interaction of Two Be Atoms. ROBERT HAMPSON, *National Bureau of Standards,* AND J. S. DOOLING, *Catholic University of America.*—Calculations of the interaction of two Be atoms have been carried out using the LCAO MO SCF approximation for six distances ranging from 3.58 A to infinity. Two ground-state calculations were performed: one using as the basis set $1s$, and $2s$ Slater orbitals for each atom; the other using $1s$, $2s$, and $2p\sigma$ orbitals. A single determinant SCF calculation for the excited state, $(\sigma_g1s)^2(\sigma_u1s)^2(\sigma_g2s)^2\times(\sigma_g2p\sigma)^2$, approximately, also was made. Curves for these states, and one including configuration interaction, will be presented. An excited state, $^3\Sigma_u$, represented by $(\sigma_g1s)^2\times(\sigma_u1s)^2(\sigma_g2s)^2(\sigma_u2s\alpha)(\sigma_g2p\sigma\alpha)$ has been calculated and will be discussed.

B4. Excited Electronic States of Linear Symmetric H_3. H. L. MORRISON AND VIRGINIA GRIFFING, *Catholic University of America.*—The Roothaan self-consistent field procedure has been applied to the problem of calculating the excited states of H_3 in the linear symmetric configuration. The excited states considered have an electron pair in a nodeless molecular orbital that consists of a linear combination of $1s$ wave functions from the respective centers. The first excited wave function—containing one electron and having one central node—is constructed from $2s$ atomic functions; a second excited orbital contains $2p$ functions instead. A third molecular orbital is a linear combination of all three $2s$ functions. The molecular orbitals of the singly occupied states are orthogonal to the doubly occupied state by virtue of symmetry. One then obtains separate Hartree-Fock equations for the open and closed shell orbitals. This type of calculation was performed for the ungerade orbitals of the $2s$ and $2p$ functions at seven values of the internuclear distance ranging from 1.4 a.u. to 2.6 a.u. Curves for both state functions exhibit minima at 1.8 a.u., when one plots total energy versus internuclear distance. The third excited state was calculated only approximately.

B5. An LCAO MO SCF Study of the Electronic States of Several Linear Hydrogen Complexes. A. R. RUFFA AND VIRGINIA GRIFFING, *Catholic University of America.*—A theoretical calculation of the potential energy curves of several linear hydrogen complexes has been made in order to study the interaction governing the kinetics of the bimolecular reaction. In particular an attempt was made to determine for what distance of approach the two diatomic molecules make a transition into the four-atom complex. Hence, the linear H_4 complex H-r-H-R-H-r-H was chosen for study. The potential energy curves indicate that two hydrogen molecules approaching on a line experience an increase in interatomic separation with the inner two atoms forming a hydrogen molecule at small separations while the outer two atoms are repelled outward from the center of the system. An additional calculation was performed on a linear chain of six hydrogen atoms with interatomic separation of two atomic units in order to get additional information regarding the relative stability of the linear hydrogen chain in comparison with other possible configurations. Computation of the total energies in the LCAO MO SCF approximation with $1s$ functions indicated that the energies of the chains of four or six H atoms generally lie between the energies of the separated hydrogen molecules and the separated hydrogen atoms.

B6. Rotational Transitions in the Collisions of Linear and Symmetric Top Molecules. GEORGE GIOUMOUSIS, *Shell Development Company and University of Wisconsin,* AND C. F. CURTISS, *University of Wisconsin.*—The previously reported[1] general theory of inelastic molecular collisions has been specialized to linear and symmetric top molecules by a method leaning heavily on the properties of the matrix representations of the three-dimensional rotation group. In the basic integral equation $\psi_i=\varphi_i+GV\psi_i$, the potential V is expanded in the representation coefficients $D^j(R)_{mn}$ and the Green's operator G in linear combinations of sharp angular momentum. The initial wave φ_i is taken to be of sharp angular momentum also. The result is a set of coupled one-dimensional integral equations, with minimal coupling as compared to other possible choices of initial state and method of expansion. Linear combinations of the solutions lead to plane wave initial states, whence to cross sections. Averaging over degenerate states, i.e., quantum number m, can be performed in closed form by the introduction of Racah coefficients. The angular dependence is expressed by an expansion in representation coefficients. Convergence is not rapid, but in one case (the angular averages needed in the kinetic theory of gases) only the first few terms of the expansion are needed.

[1] G. Gioumousis and C. F. Curtiss, J. Chem. Phys. 29, 996 (1958).

B7. Binding Energies of Li_2 and LiH. BORIS MUSULIN, DONALD K. HARRISS, AND CARL W. MITCHELL, *Southern Illinois University.*—The use of a molecular screening parameter[1] has been tested in the calculation of the binding energies of Li_2 and LiH. The calculations were made in the two-electron valence bond approximation. The screening parameter was tested separately with hydrogen and Slater orbitals. The screening parameter of three different physical models was tested for each molecule. The numerical results were similar to the results obtained in other "two electron" calculations, but the present method provided a simpler set of integrals to evaluate. Li_2 has been found to be more sensitive to the type of wave function used. The screening parameter chosen should be consistent with the physical model used in the calculation.

[1] B. Musulin, J. Chem. Phys. **25**, 801 (1956).

B8. Dissociation of Molecular Ions by Electric and Magnetic Fields.* JOHN R. HISKES, *Lawrence Radiation Laboratory, Berkeley.*—Previous calculations[1] of H_2^+ are extended to a general discussion of the dissociation of diatomic molecules and molecular ions by electric and magnetic fields. The many-electron homonuclear ions are treated in successive charge states; the HD^+, HT^+, HD, LiH^+, LiH^{++} heteronuclear systems also are considered. There are distinctly different features between the dissociation of homonuclear ions and of heteronuclear ions. For homonuclear ions in odd-charge states and for heteronuclear ions the primary mode of dissociation is a form of predissociation in which the molecular system divides into two atomic systems. Neutral molecules and homonuclear ions with even-charge states dissociate primarily via electron stripping. The HD^+ and HT^+ ions are more susceptible to dissociation than is H_2^+. The extent to which the dissociation by the Lorentz force, $\mathbf{ev}\times\mathbf{B}$, and the dissociation by an electrostatic field are equivalent is discussed.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] J. R. Hiskes and J. L. Uretsky, Bull. Am. Phys. Soc. Ser. II, **5**, 123 (1960).

B9. Approximate Analysis of Classical Scattering by a Screened Coulomb Field.* E. M. BARODY, *Battelle Memorial Institute.*—In radiation damage, as well as in various other areas, the slowing down in solids of atoms with initial energies in the range 10 kev to 100 kev is of great importance. As Bohr[1] has discussed, this process can be treated approximately by assuming a screened Coulomb repulsion between atoms and calculating scattering from classical principles. He also has emphasized the convenience of comparing exponentially screened potentials with inverse power laws. Range-energy relations obtained by this approach have proved useful in a number of investigations. In the work to be reported, Bohr's approximations have been extended and tested in several ways. Through consideration of a wide range of screening conditions, new insight has been gained into the gradual trend toward "hard-sphere" collisions which is expected when a fast atom slows down to rest.

* Supported by the Aeronautical Research Laboratories, U. S. Air Force.
[1] Niels Bohr, Kgl. Danske Videnskab. Selskab., Mat.-fys. Medd. **18**, No. 8 (1948).

WEDNESDAY MORNING AT 9:30

McConnell Engineering Building 304

(M. B. GOTTLIEB presiding)

Plasma Physics, I

C1. Superfast Pinch Experiments.* S. L. LEONARD AND L. O. HEFLINGER, *Space Technology Laboratories, Inc.*—Additional experimental results have been obtained in hydrogen with the superfast pinch device.[1] Measurement of the absolute continuum radiation intensity has confirmed previous estimates that the electron density before the main discharge is $\sim 10^{16}$ cm^{-3}. Improved image converter streak photography has shown a slower constant-velocity front following the markedly accelerating fast front previously reported. The luminosity ($\lambda = 4000$–5000 A) becomes vanishingly small throughout the observable volume immediately after the fast front reaches the axis of the pinch tube. In contrast, the arrival of the slow front at the axis creates intense central luminosity, sometimes persisting for several cycles. Magnetic probes have given additional evidence of current trapping, and single-wire probes have yielded signals of ~ 100 v rising in 3 mμsec when the fast front arrives at the probe. Equivalent results were obtained in xenon of comparable mass density. The evidence will be discussed in terms of a model in which a radially converging magnetic piston (the slow front) drives a charge separation shock wave[2] (the fast front) into the preionized plasma.

* Research supported by the U. S. Air Force, Ballistic Missile Division.
[1] L. O. Heflinger and S. L. Leonard, Bull. Am. Phys. Soc. Ser. II, **5**, 323 (1960).
[2] B. D. Fried, Bull. Am. Phys. Soc. Ser. II, **5**, 315 (1960).

C2. Transverse Pinch Studies.* M. DAZEY, V. JOSEPHSON, AND R. WUERKER, *Space Technology Laboratories, Inc.* (introduced by R. Hales).—Transverse pinch studies have been made in assemblies using deuterium gas at pressure ranging from 25 to 100 μ. Special preionization techniques allow application of the transverse pinch to a highly conducting, magnetic-field-free plasma. Smear photography and internal magnetic probe studies indicate initial shock heating of the plasma to 100-v temperatures at 50-μ pressures and subsequent controlled bouncing of the plasma sheath during the first half-cycle of the compression current. In all cases, the frequency of the bouncing is compatible with that predicted by an acoustic model. The second half-cycle exhibits the internal trapped field characteristics observed in other transverse pinch assemblies. Two methods of driving the transverse pinch have been investigated, (a) the usual condenser bank furnishing a sinusoidal current drive and (b) a fast rise constant current source.

* Research supported by the U. S. Air Force, Ballistic Missile Division.

C3. Experiments on Plasma Compression in a Rising Axial Magnetic Field (Orthogonal Pinch[1]).* J. W. MATHER AND A. H. WILLIAMS, *Los Alamos Scientific Laboratory.*—Magnetic probe data and smear photographs have been obtained for argon and deuterium discharges in straight coil geometries and with magnetic mirror ratios of 1.4 and 5.0. The magnetic phenomena characterizing plasma compression in these geometries consist of (1) hydromagnetic radial

oscillations of the plasma-field interface during the first half-cycle, (2) trapping of a reversed magnetic field throughout the gas at the beginning of the second compression cycle, and (3) the transition from the reversed to the vacuum magnetic field direction. The results show that the above phenomena are independent of the type of gas, mirror strength, and discharge frequency. As the mirror ratio is increased, measurements show (1) plasma is confined axially more efficiently, i.e., the mirror losses are reduced, and (2) the instability of the plasma is increased markedly. Attempts to confine the plasma for longer times by increasing the mirror ratio decrease the plasma end losses but increase the expected plasma instability due to field curvature.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. W. Mather and A. H. Williams, Bull. Am. Phys. Soc. Ser. II, 5, 309 (1960).

C4. Radio-Frequency Preionization of Scylla.* W. E. QUINN, E. M. LITTLE, AND F. L. RIBE, *Los Alamos Scientific Laboratory.*—Preionized operation of Scylla[1] shows that those phenomena previously observed during the second half-cycle of the magnetic compression field B_z can be advanced to the first half-cycle. Appreciable first half-cycle neutron production has been obtained by applying strong preionization from a pulsed high-power, radio-frequency system, provided that an additional quasi-static magnetic field B_θ (0.1 to 3.5 kgauss) is applied antiparallel to the direction of B_z on the first half-cycle. The neutron emission has been studied as a function of preionization power level, deuterium pressure, and B_θ. Streak photographs and magnetic probes were used to study the plasma behavior for various values and directions of B_θ. Previously similar effects were observed with a preionizer consisting of an axial discharge.[2]

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] W. C. Elmore, E. M. Little, and W. E. Quinn, Phys. Rev. Letters 1, 32 (1958).
[2] W. E. Quinn, E. M. Little, F. L. Ribe, and J. L. Tuck, Bull. Am. Phys. Soc. Ser. II, 5, 328 (1960).

C5. Hard X-Ray Emission from Scylla.* E. M. LITTLE AND W. E. QUINN, *Los Alamos Scientific Laboratory.*—Hard x rays having energies of several hundred kev have been observed during both the first and second half-cycles of Scylla's compression field B_z with weak preionization. These x rays are emitted predominantly from the central plane of the Scylla coil just before, just after, and at peak magnetic field; not at $B_z=0$ (maximum electric field) except at very low pressures. At normal deuterium pressures ($\sim$90 μ) the x rays do not occur during either half-cycle but can be induced in the first half-cycle by an applied B_θ ($\sim$2 kgauss) antiparallel to B_z. Similar values of parallel B_θ cause their emission during the second half-cycle. At lower pressures ($\sim$30 μ) less antiparallel B_θ is required for first half-cycle emission, and second half-cycle x rays occur even when parallel B_θ is zero. When the preionization is increased to high levels, the hard x rays do not occur under any of the above conditions. The experiments suggest to us that the conditions for x ray emission (runaway electrons) are not determined by single-particle orbits but rather by collective plasma phenomena which may be related to the mechanism of "shock" formation in the Scylla discharge.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

C6. Voltage Limiting in Rotating Plasma Devices.* D. A. BAKER AND J. E. HAMMEL, *Los Alamos Scientific Laboratory.*—Experiments on rotating plasma devices have shown that there is a limiting voltage for each value of magnetic field B beyond which the plasma will not sustain rotation. Possible explanations of this voltage limiting effect have been proposed: (1) breakdown across the end insulators, and (2) viscous plasma effects probably arising from interactions with neutrals. Experiments to distinguish between such phenomena in the Los Alamos device, Ixion, were performed by means of internal current measuring loops located just inside each of the end insulators. We find that no current flows on the insulators, when voltage limiting occurs, and that the limiting voltage is determined by the plasma resistance between electrodes, which is a sensitive function of the magnetic field. At higher applied voltages, currents suddenly begin to flow in the insulator region after voltage limiting has been established. It appears that, although the insulators may affect the time duration of the sustained, limited high voltage, the voltage limiting is dominated by plasma effects as in case (2).

* Work performed under the auspices of the U. S. Atomic Energy Commission.

C7. Loss of Charged Particles during Ionization in Stellarator Discharges.* R. A. ELLIS, JR., J. G. GORMAN,† AND W. STODIEK,‡ *Princeton University.*—The rise time and the peak value of the electron density have been measured as a function of the magnetic confining field and the ohmic heating voltage in the B3 Stellarator. The analysis of these data shows that charged particles are lost from the discharges during the ionization phase at rates comparable with those observed after full ionization.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† On loan from Westinghouse Electric Corporation.
‡ On leave from Max-Planck Institut fur Physik und Astrophysik, Munich.

C8. Effect of Impurities on Instabilities in The ETUDE Stellarator.* M. S. JONES, JR., *Princeton University.*—By using discharge clean-up it has been possible to obtain ohmically heated plasmas with a relatively low impurity level. It is found that, for a hydromagnetic type instability, the rate at which the plasma is lost depends inversely upon the square root of isotopic weight of the gas and is therefore dependent upon discharge purity levels. This explains the observed reduction in confinement time as a mixture of hydrogen and heavy impurity ions is replaced by a pure hydrogen discharge. No changes have been found in the conditions for the electrostatic type instabilities, other than elimination of the "steps" in the plasma current inhibition.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

C9. Life History of Impurity Ions in Zeta. W. M. BURTON AND R. WILSON, *Atomic Energy Research Establishment.*—The temporal frequency distribution of the various states of ionization of impurity ions in a hydrogen plasma is considered theoretically. A general approach is attempted in that conservation of the particles in the plasma is not assumed and, in addition to atomic processes, "discharge" processes of loss and gain of ions are considered empirically. Observations of the time variation of the intensities of resonance lines of impurity ions in zeta are made by means of a vacuum ultraviolet monochromator covering the wavelength range 500–2000 A. The solution of the relevant problem of radiative transfer shows that the assumption of proportionality between the observed spectral line intensity and the number of emitting ions is valid over the range of conditions investigated. The observations confirm the existence of the discharge processes

of loss and gain and show that these are the dominant processes governing the ion populations. The injection rate shows a large variation with the strength of the stabilizing magnetic field whereas the ion containment time is effectively constant. If we assume these processes are indicative of the hydrogen ions, there is a pump-out phenomenon in zeta which is measured and related to other discharge phenomena.

C10. Energy Loss Processes in Zeta. A. GIBSON, D. W. MASON, AND G. BARSANTI, *Atomic Energy Research Establishment.*—The processes contributing to energy loss in zeta will be discussed. It will be shown that different processes are important in different discharge conditions, and in particular that the discharge pressure has a marked effect on loss processes. Energy losses due to radiation and to fast electrons will be discussed in detail.

C11. Feasibility Study of Transient Version of Astron Thermonuclear Reactor.* C. C. CHANG,† *Lawrence Radiation Laboratory, Livermore.*—A new transient version of the Astron thermonuclear device is proposed. The heating element of plasma is the same as Christofilos' *E*-layer[1] except that it is smaller in scale. Plasma rings are generated by two homopolar devices located at opposite ends of the reactor chamber. The plasma rings injected approach one another along the *E*-layer and collide at the middle, thus heating up by shock waves. Magnetic compression is immediately applied to reduce the size of the *E*-layer and the plasma rings to smaller volume, further heating the plasma. Thermal radiation loss can be reduced. The predicted performance of the reactor is given. A number of advantages are claimed.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
† Consultant to the Lawrence Radiation Laboratory, Livermore, California, from the University of Minnesota, Institute of Technology.
[1] N. Christofilos, "Astron thermonuclear reactor," Lawrence Radiation Laboratory Reprt. UCRL-5032.

C12. Experimental Study of Explosions of High-Temperature Plasma Perpendicular to a Magnetic Field and Resulting Rayleigh-Taylor Instabilities. W. H. BOSTICK, H. DICKINSON,* J. N. DIMARCO, AND S. KOSLOV, *Stevens Institute of Technology.*—A technique[1,2] for producing plasma explosions across a magnetic field has been re-employed recently, using a new type plasma motor source. Apparent Rayleigh-Taylor flute type instabilities have been observed in plane and cylindrical geometries in homogeneous and inhomogeneous magnetic fields. Flute growth rate and wavelength have been measured as a function of magnetic field and of background pressure. The curvature of the instability jets and the distance to breakup have been measured. Branching of the flutes has been observed. Evidence of correlations with the "predications" of fluid theory have been found. Typical Kerr cell photographs will be shown and confirming probe measurements discussed. Applications to astrophysical processes are suggested.

* Captain, U. S. Army Physics Department, U. S. Military Academy.
[1] W. H. Bostick, Astrophsy. J. 127 (January, 1958).
[2] H. Dickinson, W. H. Bostick, J. N. DiMarco, and S. Koslov, Phys. Fluids 3, 480L (1960).

WEDNESDAY MORNING AT 10:00

Physical Sciences Auditorium

(W. B. LEWIS presiding)

Invited Papers in Solid and Liquid State Physics

CA1. Thermoelectric Power of the Noble Metals. A. V. GOLD, *National Research Council, Canada.* (30 min.)

CA2. Anion Diffusion in the Alkali Halides. L. W. BARR, *National Research Council, Canada.* (30 min.)

CA3. Crystal and Liquid Dynamics from Neutron Spectrometry. B. N. BROCKHOUSE, *Chalk River Laboratories.* (30 min.)

CA4. Energy-Momentum Dispersion Curves in Liquid Helium. D. G. HENSHAW, *Chalk River Laboratories.* (30 min.)

WEDNESDAY MORNING AT 10:15

McConnell Engineering Building 204

(N. F. RAMSEY presiding)

Invited Paper

D1. Paramagnetic Resonance and Relaxation. G. A. WOONTON, *McGill University.* (40 min.)

Magnetic Resonance, I

D2. Measurement of NH_3 Maser-Oscillator Frequency Noise. EDWIN L. TOLNAS, *IBM Watson Laboratory* (introduced by C. H. Townes).—An experimental measurement of maser oscillator noise has been compared, within experimental error, to a theory[1] derived from fundamental thermal considerations. The parameters P, t, and Q_l in the expression for NH_3 maser-oscillator frequency noise, $\epsilon = (kT/Pt)^{\frac{1}{2}}/2\pi Q_l$ (where ϵ is root-mean square frequency fluctuation divided by the oscillator frequency, P is maser-oscillator power, and t is effective measurement time of the recording system) were measured for two similar maser-oscillators, maser 1 and maser 2. The values ϵ_1 and ϵ_2 (ϵ for each maser) were calculated

by substitution of the measured parameters into the above expression. The frequency noise ϵ_{12} in the beat between maser 1 and maser 2 was measured and compared to its expected value $[\epsilon_1^2+\epsilon_2^2]^{\frac{1}{2}}$. The values of the measured parameters are $P_1=4.9\pm1.0\times10^9kT$, $P_2=3.0\pm0.6\times10^9kT$, $t=0.72\pm0.07$ sec, and $Q_l=3.6\pm0.5\times10^6$. P_1 and P_2 were measured by comparison with a Roger White noise source and are given in units of kT. Substitution of these values gives $[\epsilon_1^2+\epsilon_2^2]^{\frac{1}{2}}=1.2\pm0.5\times10^{-13}$. ϵ_{12}, directly measured, is $2.1\pm0.4\times10^{-13}$.

[1] C. H. Townes, Nuovo cimento Ser. X, **5**, No. 1 of Supplemento, 222 (1957).

D3. Cyclotron Resonance in Hydrocarbon Gases. R. L. COLLINS, *Phillips Petroleum Company.*—An x-band electron spin resonance spectrometer has been used to analyze the products of an electrodeless discharge in flowing gases at low pressure. The sensitivity for free radicals is such that strong signals are observed for the monatomic species H·, O:, and N· for pressures in the range 0.01 to 10 mm. During a search for polyatomic free radical fragments from hydrocarbons, a multiple signal was found near $g=2.0000$. The structure is best resolved at low pressures and consists of an asymmetric triplet at microwave power of a few milliwatts. This shrinks smoothly with decreasing power to become a much more closely spaced doublet. Evidence is presented that the signal is caused by cyclotron resonance of photo-ionized electrons. This appears to be the first case of multiple structure for an electron executing cyclotron resonance in a dilute gas.

D4. Spin-Phonon Interaction for Mn^{2+}, Fe^{3+}, and Cr^{3+} in MgO. N. S. SHIREN, *General Electric Research Laboratory.*—By utilizing ultrasonic spin resonance techniques previously reported,[1] we have measured relative phonon induced electron spin transition probabilities at 9.2 kMc for Mn^{2+}, Fe^{3+}, and Cr^{3+} in MgO crystals bonded to quartz rods. The relative product of transition matrix element x ultrasonic coupling is extracted from a comparison of the resonance saturation by ultrasonics, with the saturation by microwaves. In these preliminary experiments only longitudinal acoustic waves on the 100 axis have been used, and H_0 was rotated in the 001 plane. In all cases the interaction bandwidth is approximately the same as the observed microwave resonance line width.

[1] E. H. Jacobsen, N. S. Shiren, and E. B. Tucker, Phys. Rev. Letters **3**, 81 (1959).

D5. Ground-State Electronic Structure of Erbium and Nuclear Spins of Er^{169}, Er^{171}, and Gd^{159}.* AMADO Y. CABEZAS, INGVAR P. K. LINDGREN,† AND RICHARD MARRUS, *Lawrence Radiation Laboratory, Berkeley.*—Atomic-beam magnetic resonance studies of neutron-activated erbium and gadolinium have yielded three nuclear spins. These are $Er^{169}(I=\frac{1}{2})$, $Er^{171}(I=\frac{5}{2})$, and $Gd^{159}(I=\frac{3}{2})$. These measurements are in agreement with the assignments made from beta-ray spectroscopy and with the level diagram proposed by Nilsson.[1] Measurements of the erbium spins were made by observing the Zeeman transitions in a state characterized by $J=6$ and $g_J=1.164(5)$. It is inferred that this state almost certainly arises from almost pure L-S coupling among the electrons of the configuration $(4f)^{12}(6s)^2$ to the Hund's Rule ground state $^3H_6$. Observations of gadolinium resonances were made in the five J states arising from the ground state ^9D. The observed resonances are in agreement with g_J values previously measured.[2]

* This research was sponsored by the U. S. Atomic Energy Commission and the Office of Naval Research.
† On leave from the Institute of Physics, University of Uppsala, Uppsala, Sweden.
[1] S. G. Nilsson, Kgl. Danske Videnskab. Selskab, Matt.-fys. Medd. **29**, No. 16 (1955).
[2] K. F. Smith and I. J. Spaulding (Cambridge University, Cambridge, England) (private communication).

D6. Nuclear Spin of Ga^{70}.* V. J. EHLERS, W. B. EWBANK, W. A. NIERENBERG, F. R. PETERSEN, AND H. A. SHUGART, *University of California, Berkeley.*—The atomic-beam magnetic resonance method has been used to measure the nuclear spin $I=1$ for 21-m Ga^{70}. The resonances observed correspond to the "flop-in" transitions $(\frac{3}{2},-\frac{1}{2})\leftrightarrow(\frac{1}{2},-\frac{1}{2})$ and $(\frac{3}{2},\frac{1}{2})\leftrightarrow(\frac{1}{2},-\frac{1}{2})$ in the $^2P_{\frac{3}{2}}$ electronic state and $(\frac{3}{2},-\frac{1}{2})\leftrightarrow(\frac{1}{2},-\frac{1}{2})$ in the $^2P_{\frac{1}{2}}$ state. Four resonances have been obtained at magnetic fields between 3.5 and 9.8 gauss. The radioactive isotope was produced from stable gallium by the reaction $Ga^{69}(n,\gamma)Ga^{70}$ in the General Electric Test Reactor at Vallecitos Atomic Laboratory. In addition, a great deal of 14-hr Ga^{72} was produced by the reaction $Ga^{71}(n,\gamma)Ga^{72}$, and the nuclear spin and F-level inversion of this isotope were observed, confirming the results obtained previously elsewhere.[1] Because of the short half-life involved, the material was transported by a U. S. Navy helicopter. Detection of the beam was accomplished by collecting the atoms on sulfur-coated buttons and measuring the deposited radioactivity using continuous-flow Geiger counters.

* Supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] L. J. Kieffer, W. J. Childs, and L. S. Goodman, Bull. Am. Phys. Soc. Ser II, **4**, 10 (1959).

D7. Nuclear Spin of Lanthanum-140.* F. R. PETERSEN AND H. A. SHUGART, *University of California, Berkeley.*—The nuclear spin $I=3$ for radioactive lanthanum-140 ($T_{\frac{1}{2}}=40$ hr) has been measured in both the $^2D_{\frac{3}{2}}$ and the $^2D_{\frac{5}{2}}$ electronic states by the atomic beam magnetic resonance method. The low-frequency "flop-in" resonances which were observed at low magnetic fields correspond to the transition $F,m_F=9/2, -5/2\leftrightarrow9/2, -7/2$ in the $^2D_{\frac{3}{2}}$ state and to the transition $F,m_F=11/2, -5/2\leftrightarrow11/2, -7/2$ in the $^2D_{\frac{5}{2}}$ state. The radioactive isotope was produced from the stable metal by the reaction $La^{139}(n,\gamma)La^{140}$ in the Livermore Pool Type Reactor. Resonance detection was accomplished by collecting the radioactive atoms on sulfur-coated "buttons" which were later counted in continuous flow beta counters.

* Supported in part by the U. S. Air Force Office of Scientific Research and the U. S. Atomic Energy Commission.

D8. Neutron Activation Detection of Stable Isotopes in Atomic-Beam Research.* H. A. SHUGART AND V. J. EHLERS, *University of California, Berkeley.*—A new method for atomic-beam detection of stable isotopes has been developed and tested on Au^{197}. The stable atomic beam is collected on thin reactor-grade graphite sheets. The deposited atoms and graphite backing are then bombarded with thermal neutrons to activate the stable beam material. Because of the low cross section and low abundance of C^{13} and the long half-life of the product C^{14}, the induced carbon activity will be small compared to the activity induced in fractional microgram quantities of the deposited beam substance. Great care must be exercised in preparing the graphite collectors to prevent contamination. Feasibility of the method was demonstrated by observing atomic beam resonances in Au^{197} and verifying its known spin of $\frac{3}{2}$. After activation, the samples were counted in continuous-flow Geiger counters and with a γ-ray pulse-height analyzer. The decay curve of each sample served to establish the activated $Au^{198}(2.7d)$ content. This method should prove useful for many stable isotopes which have reasonable neutron capture cross sections and convenient reaction product half-lives.

* This research is supported in part by the U. S. Atomic Energy Commission and the U. S. Air Force Office of Scientific Research.

WEDNESDAY AFTERNOON AT 2:00

McConnell Engineering Building 204

(H. A. SHUGART presiding)

Magnetic Resonance, II

E1. Atomic Beam Studies of 27-hr Ho^{166}.* L. S. GOODMAN AND W. J. CHILDS, *Argonne National Laboratory*, AND RICHARD MARRUS, INGVAR P. K. LINDGREN, AND AMADO Y. CABEZAS, *University of California, Berkeley.*—Atomic beam studies of 27-hr Ho^{166} have been carried out independently at the two laboratories. Arguments will be presented for assigning a value $I=0$ to the nuclear spin. The weighted average of the values of g_J measured at the two laboratories is $g_J=1.19516\pm0.00010$. This is close to the value of $g_J=1.2$ that is obtained for a $^4I_{15/2}$ atomic ground state by use of Russel-Saunders coupling.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

E2. Nuclear Magnetic Interactions in Hydrogen Fluoride.* M. R. BAKER AND N. F. RAMSEY, *Harvard University.*—The radio-frequency spectrum of hydrogen fluoride has been studied by means of the molecular beam resonance method. A recently constructed beam apparatus and electron-bombardment ionization detector were used for the experiments which were carried out at magnetic fields of 900 to 3600 gauss. From an analysis of the observed spectrum, the spin-rotational constants of the proton and fluorine nuclei were determined to be, respectively, $|c_p|=71\pm3$ kcs and $|c_F|=305\pm2$ kcs. The latter is the largest spin-rotational constant yet observed, corresponding to 76 gauss per J at the fluorine nucleus. The relation of these results to other beam experiments and NMR work on fluorine compounds will be discussed.

* Work supported by the National Science Foundation and the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

E3. Radio-Frequency Spectrum of C_2H_2 and C_2D_2.* C. H. ANDERSON† AND N. F. RAMSEY, *Harvard University.*—The recent completion of a new molecular beam apparatus with an electron bombardment detector has expanded the field of molecular beam experiments to include most gases. The initial experiments were with diatomic molecules, but the work has now been extended to various polyatomic molecules including C_2H_2 and C_2D_2. The theory for the radio-frequency spectrum of C_2H_2 is similar to that of H_2, and there is only one large unknown parameter, the spin rotation constant c_p. The resonance curve is a single peak whose full width at half height is 60 kc at 300°K and 55 kc at 210°K with an intrinsic line of 17 kc with our apparatus. The best theoretical agreement with the experiment is obtained when $c_p=4.8\pm0.2$ kc. Recent work with C_2D_2 has produced a resonance curve with a narrow central peak and two symmetrical wings going out about 35 kc on either side which can be attributed to the interaction of the nuclear electric quadrupole moment of the deuteron.

* Work supported by the National Science Foundation and the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† National Science Foundation Predoctoral Fellow.

E4. Effect of Surface Collisions on the Hyperfine State of Cs^{133}.* H. M. GOLDENBERG, D. KLEPPNER, AND N. F. RAMSEY, *Harvard University.*—It has been found possible to produce resonance lines in an atomic beam apparatus, using the double oscillatory field method, which are considerably narrower than those characteristic of the same rf field separation in a conventional apparatus. The line is narrowed by a process of storing the beam in a box between the two fields.[1] The $(4,0)\rightarrow(3,0)$ hyperfine transition in Cs^{133} has been studied using a variety of surfaces in the storage box. The perturbing effects of the surface collisions shift the resonance line towards lower frequency and produce broadening of the line due to the statistical nature of the collisions. The most satisfactory surface coatings found are long chain paraffins. By using such paraffins, atoms have been stored for as many as 190 collisions, producing lines 70 cps wide and shifted by 150 cps. The rf field separation of 9 cm produces a line 2300 cps wide when the apparatus is used in the conventional fashion.

* Research supported in part by the Signal Corps and the Office of Naval Research.
[1] D. Kleppner, N. F. Ramsey, and P. Fjelstad, Phys. Rev. Letters 1, 232 (1958).

E5. Spin Relaxation in Ruby. R. A. ARMSTRONG AND A. SZABO, *National Research Council of Canada* (introduced by J. P. Hobson).—Measurements of spin relaxation in ruby (0.05% nominal chromium concentration) have been made near 3 kMc by observing the increase of susceptibility with time following saturation by a single pulse. In the nitrogen range the relaxation can be described by a single exponential; the relaxation varies with temperature as T^{-7} and is independent of θ, the angle between the crystal axis and the magnetic field. Measurements have been made at 4.2°K and 1.6°K for the $(+\frac{1}{2}\leftrightarrow-\frac{1}{2})$ transition as a function of θ. In this temperature range harmonic coupling[1] is a predominant feature, pure spin-lattice relaxation being observed for only limited ranges of θ. Coupling has been observed for ratios of the harmonic frequency to signal frequency of 2, $\frac{3}{2}$, and $\frac{1}{3}$. At harmonic points very long time constants have been observed in addition to the spin-lattice relaxation time and the time of harmonic energy sharing.

[1] W. B. Mims and J. D. McGee, Proc. Inst. Radio Engrs. 47, 2120 (1959).

E6. Quadrupole Coupling Constant and Line Widths of Al in Ruby as a Function of T and Cr^{3+} Concentration.* W. J. VEIGELE,† W. H. TANTTILA, AND C. M. VERBER, *University of Colorado.*—In ruby the quadrupole coupling constant $\Delta\nu$ and the line widths of Al were investigated at 300°K, 77°K, and 4.2°K and Cr^{3+} impurity concentrations of 0.1%, 1.5%, and 4%. The value of $\Delta\nu$ at 300°K agreed with that obtained by Pound.[1] It was found that $\Delta\nu$ decreased 3 kcps with a decrease in T from 300°K to 4.2°K and was independent of the Cr^{3+} concentration. Broadening of the lines with a decrease in T was observed as shown below, where $\Delta\nu_{\frac{1}{2}}$ is the average value of the central line width over a number of crystal orientations in the magnetic field.

$\Delta\nu_{\frac{1}{2}}$(kcps)	0.1%	1.5%	4%
300°K	7.41	6.99	7.18
77°K	8.46	8.64	7.93
4.2°K	10.5	10.3	15.5

The satellite line widths were observed to be equal to the values of $\Delta\nu_{\frac{1}{2}}$. The results will be discussed further.

* Supported by the U. S. Air Force and National Science Foundation.
† Now at Parsons College.
[1] R. V. Pound, Phys. Rev. 79, 685 (1950)

E7. Hyperfine Structure of the $^2P_{\frac{3}{2}}$ State and the Nuclear Electric Quadrupole Moment of Be^9. ALLEN LURIO AND A. G. BLACHMAN, *IBM Watson Laboratory.*—The hyperfine

structure of $Be^9(I=\frac{3}{2})$ in its metastable $^3P_2$ atomic state has been measured by the atomic beam magnetic resonance method. The metastable state is produced by electron bombardment and detected by electron ejection from a cesium surface. Preliminary measurements of the hyperfine structure intervals are $\Delta\nu(\frac{7}{2},\frac{5}{2})=435.45\pm0.05$ Mc/sec, $\Delta\nu(\frac{5}{2},\frac{3}{2})=312.10\pm0.07$ Mc/sec, $\Delta\nu(\frac{3}{2},\frac{1}{2})=187.5\pm0.15$ Mc/sec. From these measured hyperfine structure intervals the dipole and quadrupole coupling constants are computed to be $a=124.63\pm0.1$ Mc/sec, $b=0.85\pm0.1$ Mc/sec. From the b coefficient and the value of $\langle(1/r^3)\rangle$ for the $2p$ electron computed from the Hartree-Fock wave function for the $^3P_2$ state, the quadrupole moment of Be^9 is found to be $Q=+0.03\times10^{-24}$ cm^2. Transitions between hyperfine structure levels in the $^3P_1$ state also have been observed and will be discussed.

E8. Bond Asymmetries from Zeeman-Split Nuclear Quadrupole Resonance.* VICTOR REHN† AND C. DEAN, *University of Pittsburgh.*—Improved techniques have made it feasible to use relatively high Zeeman fields (H) to obtain accurate measurements of the asymmetry parameter (η) from relatively complex NQR spectra from nuclei of spin $\frac{3}{2}$. The relevant theoretical details have been examined, and a method developed for obtaining η from field and frequency measurements alone. Since η is assumed to be directly related to the electronic configuration in the covalent bond, data of this precision can provide an experimental test of the relative importance of σ and π bonding. The results indicate the differences encountered: $\eta=0.076\pm0.003$ in p-Cl_2 benzene; $\eta=0.0489\pm0.002$ in p-Cl aniline; $\eta=0.116\pm0.002$ for bonds with the lower pure NQR frequency in 1245 Cl_4 benzene. By writing the first-order expressions for the α and β Zeeman components with H perpendicular to the bond axis, but using the average of field for $\nu_{\text{applied}}-\nu_0=\pm\text{const}$, where ν_0 is the pure NQR frequency, terms proportional to H^2 cancel, and $\eta=2(\bar{H}_\alpha-\bar{H}_\beta)/(\bar{H}_\alpha+\bar{H}_\beta)$ irrespective of azimuthal angle of H. Terms proportional to H^3 are observed at $H>2400$ oe. For ultimate accuracy numerical data processing may be used. Experiment and theory show strong intensity variations which place restrictions on the experimental geometry.

* Supported by the U. S. Air Force Office of Scientific Research (ARDC).
† Present address: Physics Division, Armour Research Foundation.

E9. Temperature Dependence of the Pure Nuclear Quadrupole Resonance Frequency in $KClO_3$.* JACQUES VANIER, *McGill University* (introduced by G. A. Woonton).—The pure nuclear quadrupole resonance frequency of Cl^{35} in $KClO_3$ has been measured as a function of temperature from 16.5°K to 273.16°K. The results are compared with Bayer's theory; agreement is excellent below 80°K. The possibility of using this temperature dependence as the basis of a sensitive thermometer has been studied.

* Supported by Defence Research Board.

E10. Deuteron Magnetic Resonance Spectrum in Deuterated Rochelle Salt.*† JOHN L. BJORKSTAM AND EDWIN A. UEHLING, *University of Washington.*—Although the dielectric anomalies associated with ferroelectric materials were first discovered in Rochelle salt [NaK(tartrate)·4 H_2O], the complexity of the crystal structure has precluded, to date, a complete analysis. To complement the available neutron diffraction, infrared, and NMR data we have undertaken an investigation of the NMR spectrum of the deuterated crystal. Upon deuteration, all but 2 of the 12 protons in the RS molecule are replaced. As a result of the quadrupolar splitting, this large number of nonequivalent deuterons leads to a very complex spectrum. The over-all splitting is of the order of 200 kc/s. The relaxation time T_1 is less than 1 sec and depends on factors which have to be studied in detail. The nature of the spectrum and its dependence on temperature will be described.

* Supported in part by the U. S. Air Force Office of Scientific Research.
† Crystals obtained from Dr. Hans Jaffe of the Clevite Corporation, Research Division.

E11. Domain Effects in the Deuteron Magnetic Resonance Spectrum of KD_2PO_4.z EDWIN A. UEHLING AND JOHN L. BJORKSTAM, *University of Washington.*—In a previous report[1] attention was called to an additional splitting which occurs in the NMR spectrum of the deuteron in the ferroelectric KD_2PO_4 when the crystal is cooled below the Curie temperature. Since the crystal had not been poled into a single domain, the additional splitting was attributed to alternately polarized domains. The magnitude of this additional domain splitting was reasonably consistent with the shear known to occur when the crystal polarizes spontaneously. It was subsequently called to our attention[2] that the possible effects of alternately positioned deuterons in the double minimum hydrogen bond potential and the different frequencies of shuttling between these positions above and below the Curie temperature should be investigated. Consequently we have studied the resonance in the presence of an electric field. These experiments show that polarization of the crystal causes one set of the split lines to disappear. Reversing the direction of polarization brings out the second set of lines in place of the first. These results seem to confirm the belief that the splitting in question is a domain effect.

* Supported in part by the U. S. Air Force Office of Scientific Research.
[1] John L. Bjorkstam and Edwin A. Uehling, Phys. Rev. **114**, 961 (1959).
[2] Lars Onsager (private communication).

WEDNESDAY AFTERNOON AT 2:00

Chemistry Amphitheatre

(G. N. WHYTE presiding)

Nuclear Physics II: Nuclear Reactions

F1. Angular Dependence of Proton Polarization in $Be^9(d,p)Be^{10}$.* JOHN A. GREEN AND W. C. PARKINSON, *University of Michigan.*—The polarization of the protons from the ground and first excited states of Be^{10} resulting from the $Be^9(d,p)Be^{10}$ reaction has been measured for several forward scattering angles using 7.8-Mev deuterons from the University of Michigan cyclotron. The analysis apparatus[1] consists of a low-resolution magnetic spectrometer in conjunction with a helium polarimeter using eight photographic plates azimuthally arranged around the analyzed proton beam. Measurements of the polarization for the ground state at angles less than the stripping minimum indicate that the polarization is minus along the quantization axis $k_p\times k_d$ when the angular momentum of the captured neutron is $j_n=l_n+\frac{1}{2}$ in agreement with all previous measurements. For the first excited state the sign of the polarization indicates pre-

dominantly $j_n = l_n + \frac{1}{2}$ capture if the sign rule holds. The angular dependence of the polarization will be discussed with respect to the angular distribution of the protons from the reaction.

* Supported in part by the U. S. Atomic Energy Commission.
[1] J. C. Hensel and W. C. Parkinson, Phys. Rev. 110, 128 (1958).

F2. $Be^9(d,p)Be^{10}$ (Ground State) Reaction at $E_d = 7.8$ Mev.* C. R. LUBITZ, *University of Michigan.*—The proton angular distribution and polarization have been computed on the cutoff plane wave theory previously described,[1] assuming pure $p_{\frac{1}{2}}$ capture. The experimental peak[2] can be fitted with a neutron square well radius of $4f$ if the incident wave falls to half amplitude at r_n or $r_p = 5.2f$. This represents an "average extinction distance," since a spherically symmetric cutoff is employed.[1] A surface-type absorptive potential 7–9 Mev deep, appropriate to nucleons of energy one-half E_d, provides a roughly isotropic background to the angular distribution and a polarization distribution in reasonable agreement with the measurements presently available.[3] Interpolating between absolute cross sections, 0.31 f^2/sr at 3.6 Mev and 0.54 f^2/sr at 14.5 Mev, yields a reduced width about 1.9 times the square-well single-particle value. The intermediate-coupling value for this number is about 2.0, the Butler theory prediction about 0.2.

* Supported in part by the U. S. Atomic Energy Commission.
[1] C. R. Lubitz, Bull. Am. Phys. Soc. Ser. II, 5, 18 (1960).
[2] J. R. Holt and T. N. Marsham, Proc. Phys. Soc. (London) **66A**, 1032 (1953).
[3] Preceding abstract.

F3. Decay Schemes of the 9.28-, 9.19-, and 8.92- Mev B^{11} Levels from $Li^7(\alpha\gamma)B^{11}$ Reaction. P. P. SINGH* AND G. M. GRIFFITHS, *The University of British Columbia.*—The University of British Columbia Van de Graaff generator was used to study the resonant capture of α particles by Li^7 to form B^{11} in the three excited states at 8.92 Mev, 9.19 Mev, and 9.28 Mev. The γ rays emitted were detected by means of 3.5-in. and 4.5-in. NaI crystals. The energies, intensities, and the angular distributions of the γ rays which de-excite the three states of B^{11} were studied and the radiation widths and the α-particle widths were calculated. The details of these results will be presented along with the conclusions drawn about the spins and the parities of the 4.46, 6.76, 8.92, 9.19, and 9.28 Mev B^{11} states from these investigations.

* Now at Atomic Energy of Canada Ltd., Chalk River, Ontario.

F4. Photodisintegration of C^{12} Yielding Alpha Particles. M. ELAINE TOMS, *U. S. Naval Research Laboratory.*—Nuclear emulsions exposed to a hardened bremsstrahlung beam of 21.5-Mev maximum energy were processed in a manner which minimized fogging and permitted the variation in ionization along the paths of alpha particles to be observable. A total of 238 events due to the $C^{12}(\gamma,3\alpha)$ reaction have been distinguished from other alpha-producing reactions in the emulsion. Calculations were performed by using an L.G.P.-30 electronic computer. The program eliminated the effects of photon momentum. The cross section obtained is quite similar to that found by Goward and Wilkins.[1] Since this reaction may proceed as $C^{12}(\gamma,\alpha)Be^8 \rightarrow 2\alpha$, the three possible Be^8 excitations, E_x, were calculated for each star. The energy uncertainty inherent in the measurements was about ± 0.3 Mev. Twenty-one stars had an E_x value within the limits (-0.24 to $+0.45$ Mev) for the ground state. For the broad 2.9-Mev excited state of Be^8, limits of 2.25 to 3.74 Mev were chosen. At least one E_x value in this range was found for 166 stars. The remaining 51 stars, or about 20%, had no E_x value corresponding to either the ground state or the 2.9-Mev state.

[1] F. K. Goward and J. J. Wilkins, Proc. Roy. Soc. (London) **A217**, 257 (1953).

F5. Angular Distribution of the Ground-State Neutrons from the $C^{13}(p,n)N^{13}$ and $N^{15}(p,n)O^{15}$ Reactions.* C. WONG, J. D. ANDERSON, S. D. BLOOM, J. MCCLURE, AND B. D. WALKER, *Lawrence Radiation Laboratory, Livermore.*—It has been suggested by Bloom, Glendenning, and Moszkowski[1] that one may be able to deduce the effective neutron-proton interaction inside a nucleus by studying the ground state (p,n) reaction on mirror nuclei. This experiment was performed to supply the needed data. The angular distribution of the ground-state neutrons from the $C^{13}(p,n)N^{13}$ and $N^{15}(p,n)O^{15}$ reactions has been measured in 10° steps from 0° to 150° and for incident proton (laboratory) energies of approximately 6.5, 6.9, 7.5, 8.0, 8.5, 9.0, 9.5, 10.5, and 12.5 Mev. A calibrated plastic scintillator was used in order to obtain absolute differential cross sections. Time-of-flight techniques[2] on the Livermore variable energy cyclotron allowed positive identification of the ground-state neutrons. The targets [CO_2(58% C^{13}) and N_2(90% N^{15})] were sufficiently thick to average out the effects of possible compound nucleus contributions. The theoretical fits and implications are discussed in the next paper.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] S. D. Bloom, N. K. Glendenning, and S. A. Moszkowski, Phys. Rev. Letters 3, 98 (1959).
[2] C. Wong, J. D. Anderson, C. C. Gardner, J. W. McClure, and M. P. Nakada, Phys. Rev. 116, 164 (1959).

F6. Proton-Neutron Interaction and the (p,n) Reaction in Mirror Nuclei.* N. K. GLENDENNING AND S. D. BLOOM, *Lawrence Radiation Laboratory.*—In an earlier paper[1] (called I) it was suggested that the (p,n) reaction connecting the ground states of mirror nuclei may provide a good method of studying the effective two-nucleon potential in the nucleus. In paper I we gave plausible arguments for believing that this particular reaction singles out the charge exchange part of the effective interaction. In this paper we present the results of an analysis of the experimental data reported in the preceding paper. Distorted waves corresponding to a complex square well were used to describe the free nucleons, and the reaction was assumed to occur near the nuclear surface.[2] A central potential was used for the interaction, and it was divided into singlet and triplet parts. It was found that the potentials that best fit the experimental data (excluding some resonance regions) require different signs for the singlet and triplet components with somewhat weaker triplet interaction. Details pertaining to these results will be discussed.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] S. D. Bloom, N. K. Glendenning, and S. A. Moszkowski, Phys. Rev. Letters 3, 98 (1959).
[2] N. K. Glendenning, Phys. Rev. 114, 1297 (1959).

F7. Elastic Scattering and Reactions of Protons on Argon-40.* A. C. L. BARNARD AND C. C. KIM, *State University of Iowa.*—Thin targets of natural argon gas were bombarded with protons in the energy range 800–3500 kev. Differential cross sections were measured at three angles for elastic scattering and for the $A^{40}(p,p')A^{40*}$ and $A^{40}(p,\alpha)Cl^{37}$ reactions. Strong anomalies were observed in the elastic-scattering cross section at 1.88, 2.45 (these two corresponding to the anomalies reported by Freier *et al.*[1]), and 3.4 Mev, and many other anomalies also were observed. However, the anomalies corresponding to the previously reported[2] $A^{40}(p,\gamma)K^{41}$ resonances were found to be small. In the range of incident proton energies between 2.4 and 3.4 Mev there were about 35 resolved or partly resolved resonances in the yield of α particles.

* Supported in part by the U. S. Atomic Energy Commission.
[1] G. D. Freier, R. F. Famularo, D. M. Zipoy, and J. Leigh, Phys. Rev. 110, 446 (1958).
[2] Brostrom, Huus, and Koch, Nature 162, 695(L) (1948).

F8. Evidence for Compound Nucleus Formation Using (p,p') Scattering in Ni^{58}.* RAYMOND FOX AND RICHARD ALBERT, *Lawrence Radiation Laboratory, Livermore.*—Inelastic proton spectra were obtained from Ni^{58} using incident proton energies of 7.8, 8.4, 9.15, 10.05, 11.25, and 11.4 Mev. The inelastic proton spectra extended from 2 Mev up to the incident energy. S, the differential scattering cross section divided by the emitted proton energy and the Coulomb cross section, was plotted as a function of the excitation of the residual nucleus. The curves are strikingly the same when normalized at one point even though there is appreciable structure in the data. Only the formation of a compound nucleus to our knowlege predicts such a high correlation of S. Another interesting result of all our data is a large peak at 4.75-Mev excitation energy of the residual nucleus. This is in an energy region where the level density is sufficiently high so that it is difficult to attribute this peak to a single level.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

F9. Cross Sections of (p,pxn) Reactions in Au^{197}. T. M. KAVANAGH, *McGill University* (introduced by R. E. Bell).—Cross sections of the (p,pn), $(p,p2n)$, and $(p,p3n)$ reactions in Au^{197} have been measured by the activation method for incident proton energies up to 86 Mev. This method does not distinguish whether or not the outgoing particles are bound, e.g., the measured (p,pn) cross section includes the (p,d) cross section. The curves of cross section as a function of proton energy show similar shapes for the three reactions, rising from apparent thresholds at 16, 21, and 30 Mev, respectively. The effect of the (p,t) reaction shows as a relative lowering of the apparent $(p,p2n)$ threshold. The cross sections rise to peaks of 180, 145, and 150 mb, respectively, at proton energies about 30 Mev higher than their respective apparent thresholds. These cross sections are an order of magnitude larger than those predicted on the statistical model. The reactions are interpreted in terms of initial quasi-free two-body interactions in the diffuse edge of the nucleus.

F10. Prompt Neutron Emission and Kinetics of Spontaneous Fission. S. L. WHETSTONE, JR., *Los Alamos Scientific Laboratory.**—The availability of a premium quality Cf^{252} source[1] has permitted a remeasurement of the prompt neutron emission from single fission fragments reported previously.[2] About 100 000 events have been recorded, reducing statistical uncertainties by a factor approaching one-fourth. The improved quality source decreased dispersions in fragment kinetics measurements to agree with known timing uncertainties. The dependence of the average number of prompt neutrons per fragment as a function of fragment mass measured with the improved mass resolution of the present experiment shows a slightly more pronounced discontinuity at the symmetric mass mode—evidence that the true dependence is even more discontinuous. Fragments were detected in unequal solid angles in the present experiment, decreasing possible biases due to effects correlated with noncollinearity of the fragment pairs. The present experimental arrangement, including the 8-in. diameter fragment detectors, has been developed for the study of spontaneous fission of Cm^{244}. Such data will be presented as are available.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] Kindly provided by S. G. Thompson and group, LRL.

[2] S. L. Whetstone, Jr., Phys. Rev. **114**, 581 (1959).

F11. Radiochemical Studies of Neutron-Induced Fission of U^{235} and U^{238}.* H. B. LEVY, H. G. HICKS, W. E. NERVIK, P. C. STEVENSON, J. B. NIDAY, AND J. C. ARMSTRONG, JR., *University of California, Livermore.*—Neutron fluxes of various mean energies, which were obtained by bombarding different materials with protons, deuterons, and alpha particles from the Berkeley 60-in. cyclotron, were used to induce fission in U^{235} and U^{238} targets. Radiochemical methods were used to determine cumulative fission yields of several nuclides relative to that of one standard nuclide. When the relative fission yield of one of the nuclides is arbitrarily chosen to be the independent variable and the corresponding relative fission yields of the others are plotted against it, two sets of straight lines are obtained, one set for U^{235} and one for U^{238}. One possible explanation for these straight-line relationships can be given in terms of a combination of two types of fission (e.g., symmetric and asymmetric), the relative proportions of which change with excitation energy.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

WEDNESDAY AFTERNOON AT 2:00

Moyse Hall

(A. R. HUTSON presiding)

Electron Emission

G1. Structure of Cesium Bismuth Photosurfaces. R. J. ZOLLWEG AND C. R. TAYLOR, *Westinghouse Research Laboratories.*—Harper and Choyke[1] found that cesium bismuth photosurfaces prepared on a tin oxide on glass substrate exhibited a marked increase in photoemissive yield when the photosurface was cooled below about −90°C. We have obtained similar results by admitting oxygen at the appropriate time during processing and have investigated the various parameters of the processing required for enhancing the effect. The results were found to be strongly dependent upon the temperature of the substrate during the evaporation of the bismuth and on the rate of evaporation. This suggested that the structure of the photosurface plays a significant role. After measuring the temperature dependence of the photoyield, replicas of several photosurfaces were prepared by evaporating SiO_2 in the vacuum. These were examined by electron microscopy and a correlation found between the size of particles making up the photosurface and the ratio of the yield at liquid nitrogen temperature to that at room temperature. A change in electron mean free path with temperature may be the mechanism responsible for the change. Energy spectra of the photoelectrons obtained from retarding potential measurements showed structure but no large differences with temperature.

[1] W. J. Harper and W. J. Choyke, Rev. Sci. Instr. **27**, 966 (1956).

G2. Secondary Electron Emission of Alkali Halide Single Crystals Cleaved in High Vacuum. N. REV WHETTEN, *General Electric Research Laboratory.*—The secondary electron

emission yield of several alkali halide single crystals has been determined immediately after cleaving the crystals in a high vacuum of 10^{-10} mm Hg. Only a small fraction of a monolayer of gas could be adsorbed on the surface of the freshly cleaved crystal before the measurements were completed. Single pulse measurement techniques were employed to minimize charging of the surface and damage to the crystals. Some of the crystals examined and their corresponding yield after cleaving in a high vacuum are NaBr-23; KBr-14; KI-10; KCl-13; NaCl-14.

G3. Kinetics of Strontium on a Tungsten Single Crystal.* E. A. COOMES AND B. E. BARNABY, *University of Notre Dame.*—Field electron microscopy shows that strontium deposited on a tungsten single crystal will migrate with a boundary at 350°K. If the deposit is sufficiently large, Sr will produce its own fcc structure in epitaxy with the W. The {110} of Sr makes contact with the {112} of *W*. This modification has the lowest work function obtained with the Sr-W system. The adcrystal is stable at 630°K but may be desorbed completely on increase of temperature to 1250°K.

* Supported in part by Office of Naval Research.

G4. Contribution of Backscattered Electrons to Secondary Electron Formation in Solids. H. KANTER, *Westinghouse Research Laboratories.*—The secondary electron emission properties of solids are strongly dependent on the scattering process of the primary electrons[1,2] for which there does not as yet exist any detailed theory. The problem is somewhat simplified in the case where the penetration depth of the primaries is much larger than the escape depth of the secondary electrons. Under this condition the primaries pass through the escape region along a nearly straight path. The backscattered electrons from the interior of the material emerge through the escape region with reduced energy, following a cosine distribution.[3] It is shown experimentally that, for aluminum with a relatively small backscattering coefficient of $\eta_B \sim 0.15$, about $\frac{2}{3}$ of the observed secondary electrons are produced by the backscattered electrons. This result agrees approximately with what one would expect from the larger rate of energy loss and the larger path lengths of the backscattered electrons in the escape region compared to that of the incoming primaries. Similar measurements on gold indicate a relatively smaller efficiency of the backscattered electrons in forming secondaries.

[1] E. J. Sternglass, Westinghouse Research Lab. Sci. Paper No. 1772 (1954).
[2] A. J. Dekker and R. G. Lye in WADC Technical Rept. 57-760 by W. G. Shepherd.
[3] H. Kanter, Ann. Phys. **20**, 144 (1957).

G5. Field-Dependent Photoelectric Emission from Molybdenum.* R. C. JAKLEVIC AND D. W. JUENKER, *University of Notre Dame.*—Photoelectric emission from a 5-mil single-crystal Mo wire at 1000°K has been measured for accelerating fields from 0.8 to 142 kv/cm, employing monochromatic light between 238 and 297 mμ. Above 3.6 kv/cm, the data are in good agreement with the Fowler-Schottky expression suggested by Guth and Mullin[1] in which a nearly quadratic dependence of photocurrent on the square root of the applied field is predicted. Observed threshold energies increase from 4.44 to 4.52 ev with decreasing wavelength, as is expected for emitters of nonuniform work function. Two illumination directions, separated azimuthally by 90°, gave identical results. Fowler plots for room temperature and 1000°K yield identical thresholds of 4.41 ev, and a Richardson-plot determination of the thermionic emission constants yields $e\phi = 4.33$ ev and $A = 38$ amp/cm²-deg². Comparison of measured thresholds from Mo with past determinations reveals a consistent dissimilarity between values obtained from sheet and wire samples, the latter yielding higher values. A possible reason for this is the exclusion of directions in the vicinity of ⟨321⟩ from the surface of wires with [110] axes; for Mo these directions are known to be highly emitting.

* Partially supported by the U. S. Atomic Energy Commission.
[1] E. Guth and C. J. Mullin, Phys. Rev. **59**, 867 (1941).

G6. Thermionic Emission from Cesium Films on Single Crystal Base Metals. HAROLD F. WEBSTER, *General Electric Research Laboratory.*—Thermionic emission has been observed from single crystal cathodes of tantalum, nickel, and silver when they are heated in a cesium atmosphere. Emission current has been measured as a function of both cathode temperature and cesium pressure, and *S* curves similar to those obtained by Taylor and Langmuir[1] for tungsten in cesium have been obtained. The height of the low-temperature peak and the position of this peak along the temperature scale varies not only with the material but also with the exposed crystal face of the cathode metal. Results will be presented for some of the low index planes.[2]

[1] J. B. Taylor and I. Langmuir, Phys. Rev. **44**, 423 (1933).
[2] Supported by Air Force Cambridge Research Center.

G7. Oxide Cathode Emission Decay as a Bimolecular Rate Process. JEROME ROTHSTEIN, *Edgerton, Germeshausen and Grier, Inc.*—The short-time thermionic emission decay in oxide cathodes studied by Sproull[1] and others is considered from the point of view of bimolecular rate processes. The equations developed would apply equally well to migrating barium or oxygen ions as the responsible entity, to the oxide surface, the metal-oxide interface, or the bulk as the seat of the rate governing processes, or to the effects of poisons, e.g., gas-adsorbed on the anode, freed by the passage of current. The rate equation is a generalization of one derived as an approximation by Sproull. It has two solutions depending on the initial conditions, one governing decay, the other recovery. These are hyperbolic cotangent and tangent functions, respectively. The simple analytical form of the solutions makes comparison with experiment relatively straightforward and may permit considerable insight into the fundamental processes involved in decay specifically and cathode kinetics generally.

[1] R. L. Sproull, Phys. Rev. **67**, 166 (1945).

G8. Temperature Dependence of the Work Functions of Single Crystal Surfaces of Copper.* E. H. BLEVIS† AND C. R. CROWELL, *McGill University* (introduced by G. A. Woonton).—Measurements of the temperature dependence of the work functions of the (100), (110), (111), (211), and (221) crystal faces of copper have been taken from 300°K to 900°K. The results exhibited distinct curvatures varying from face to face. A polar plot of $d\phi/dt$ at 600°K about a 110-zone axis suggests maxima in the 100 and 110 directions of -1.4 and -0.52×10^{-3} ev/°K and a minimum of -3.4×10^{-3} ev/°K in the 111 direction. The crystal surfaces were prepared by electropolishing and extensive high-vacuum degassing, and the crystals were mounted in a specially designed support to avoid stresses when heating and cooling. Measurements were taken in sealed-off tubes in vacua of the order of 10^{-9} mm Hg and were reproducible and free from evidence of contamination. The shift in diode characteristics accompanying changes in the anode work function was observed. A constant current generator determining the diode current and an electrometer monitoring the anode voltage permitted continuous recording of changes in the anode work function and hence a sensitive measure of the growth of any contaminating surface layer.

* Supported by Defence Research Board, Ottawa.
† Now at Pacific Semiconductors Inc.

G9. Temperature Dependence of the Work Functions of Single Crystal Surfaces.* C. R. CROWELL AND E. H. BLEVIS,† *McGill University* (introduced by G. A. Woonton).—Measure-

ments of the temperature dependence of the work functions of the (100) and (111) faces of copper can be used to demonstrate the consistency of low-temperature photoelectric[1] measurements and thermionic[2] measurements at the melting point. Bolshov's conclusion that the work function of copper varies continuously through the melting point is reinforced by these measurements and by general thermodynamic considerations. Surface effects are shown to be a predominant influence on the temperature dependence of the work function over a wide range of temperature. Re-examination of thermionic measurements on tungsten[3] exhibits a general confirmation of these ideas.

* Supported by Defence Research Board.
† Now at Pacific Semiconductors Inc.
[1] N. Underwood, Phys. Rev. **47**, 502 (1935)
[2] V. G. Bolshov, Bull. acad. sci. U.R.S.S. Sér. phys. **20**, 1128 (1956).
[3] G. F. Smith, Phys. Rev. **94**, 295 (1954).

G10. Electron Diffraction and Work-Function Studies of Adsorption and Initial Oxidation on a (100) Nickel Crystal Surface.* H. H. MADDEN AND H. E. FARNSWORTH, *Brown University.*—Low-energy (10–200 ev) electron-diffraction and photoelectric work-function measurements have been made in a single experimental tube, using normal incidence for diffraction and 45° incidence for ultraviolet light. As the oxygen exposure at room temperature increases, the work function φ increases from 5.14 ev for clean nickel (obtained by ion bombardment and a small anneal) to a value >5.5 ev, followed by a slow decrease to 5.34 ev where an oxide begins to form and where φ drops abruptly to <5.0 ev. The initial increase in φ is associated with surface adsorption[1]; the decrease from >5.5 to 5.34 is tentatively associated with a place exchange of oxygen and nickel which is also accompanied by a small increase (4 to 5%) in the lattice constant. Both work-function and diffraction data indicate that nitrogen does not adsorb on the clean (100) nickel surface. CO adsorbs in both an oriented lattice structure as well as a polycrystalline structure. The presence of CO on the surface does not delay appreciably the formation of the oxide.

* This work is supported by Office of Ordnance Research, U. S. Army.
[1] H. E. Farnsworth and Johannes Tuul, J. Phys. Chem. Solids **9**, 48 (1959).

G11. Electron Diffraction and Secondary Electron Emission Studies of a (100) Semiconducting Diamond Surface.* H. E. FARNSWORTH AND JOHN MARSH, *Brown University.*—When normal incidence on the (100) face was used, the low-energy (below 350 ev) electron-diffraction pattern, after outgassing of the crystal below 1000°C, contained no half-integral order surface grating beams in either the (100) or (110) azimuths, thus indicating that the positions of the atoms in the surface monolayer are not altered by the surface discontinuity as was found previously for germanium and silicon. This result is consistent with the microcleavage experiments of Wolff and Broder.[1] The secondary electron emission coefficient increased from 0.3 at 5 ev to a maximum of 1.45 at 300 to 400 ev for the diamond surface. Heating of the crystal support for 2 days at 1050°C caused a decrease in the intensity of the diffraction pattern. Argon-ion bombardment caused the diffraction pattern to disappear completely. Subsequent heating of the crystal support at 1100°C did not reproduce the diffraction pattern. As a result of this treatment, the maximum secondary emission coefficient decreased to 0.9 at 250 ev. The diamond surface may be regenerated by exposure to aqua regia and subsequent heating in vacuum.

* Assisted by U. S. Signal Engineering Laboratories. The diamond was kindly furnished by Dr. J. F. H. Custers, Crown Mines, Johannesburg, South Africa.
[1] G. A. Wolff and J. D. Broder, Acta Cryst. **12**, Pt. 4, 313 (1959).

WEDNESDAY AFTERNOON AT 2:00

Physical Sciences Auditorium

(HENRY HURWITZ, JR., presiding)

Invited Papers of the Divisions of Fluid Dynamics and Plasma Physics

GA1. Our Present Understanding of Turbulence. LESLIE S. G. KOVASZNAY, *The Johns Hopkins University.* (45 min.)

GA2. Turbulence Convection in Stars. MARTIN SCHWARZSCHILD, *Princeton University.* (30 min.)

GA3. Solar Flares and Their Effects in the Surrounding Atmosphere of the Sun. WALTER O. ROBERTS, *University of Colorado.* (30 min.)

GA4. Radiation Losses from a Stabilized Pinch Discharge. HUGH J. KARR, *Los Alamos Scientific Laboratory.* (30 min.)

WEDNESDAY AFTERNOON AT 2:00

McConnell Engineering Building 304

(B. D. FRIED presiding)

Plasma Physics, II

H1. Conical Pinch Plasma Accelerator.* C. W. HARTMAN, S. A. COLGATE, AND R. MUNGER. *Lawrence Radiation Laboratory, Livermore.*—Experimental results of deuterium plasma acceleration by a conical dynamic pinch discharge are described. Pulsed gas input is used to obtain instantaneous pressure from 100–500 μD_2. The discharge chamber consists of a truncated quartz cone (half angle 3°) placed between normal end electrodes. Plasma is ejected into an evacuated drift

region through an axial orifice in the large end electrode. Time-of-flight measurements indicate plasma is ejected at about the first bounce time with velocity roughly equal to the axial phase velocity of the conical shock (4×10^7 cm/sec). The majority of the accelerated plasma is contained within a velocity spread of 50%. Diamagnetic signals of a thousand gauss are observed 50 cm from the orifice, indicating accelaration of substantial quantities of plasma free of self-magnetic field. Detectable diamagnetic signals are also observed for ion energies up to 50 kev.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

H2. High-Speed Hydromagnetic Gun.* J. E. OSHER AND D. C. HAGERMAN, *Los Alamos Scientific Laboratory.*—A coaxial plasma gun[1] has been built which produces a short (2–5 μsec) burst of energetic deuterium plasma (mean plasma velocity of 50 cm/μsec, maximum velocity of ~180 cm/sec). The electrical characteristics of the gun are determined by the stainless steel coaxial central and outer electrodes with radii 2.5 and 4.8 cm, respectively, and the 1.7 μf condenser bank (operated at 20 kv). The gun rings with maximum gun current of 70 ka and a full period of 2.7 μsec. The velocity and quantity of ejected plasma depend critically on the initial mass (optimum performance $\sim1.6\times10^{18}$ deuterons) and purity of the gas injected by the fast inlet valve. To accelerate $\sim10^{17}$ deuterons out the gun muzzle, it was found necessary to shorten the length of the central electrode to ~15 cm. An analysis of the plasma 160 cm from the gun muzzle shows that ~70% are neutral energetic atoms. Performance of a similar gun driven by a higher energy condenser bank is described.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. Marshall, Phys. Fluids 3, 134 (1960).

H3. Injection and Containment Experiments in a Picket Fence Geometry.* D. C. HAGERMAN AND J. E. OSHER, *Los Alamos Scientific Laboratory.*—The hydromagnetic plasma gun described in the previous paper has been used to inject plasma into a magnetic biconical cusped geometry (line cusp radius 20 cm, distance between axial cusps 40 cm, maximum cusp field 15 kg) to test the entropy trapping principle.[1] It is possible to create a region of high β (~1) plasma ($r\sim5$ cm) at the center of the cusp geometry for low magnetic fields (60 gauss) when injecting low-velocity (14 cm/μsec) plasma. This high β region has a mean lifetime of ~30 μsec with an input pulse lasting ~2.5 μsec (input cusp "open" time). Magnetic probes distinctly interfere with the plasma so that the region of high β cannot be mapped in detail. Estimates on temperature and density imply that thermalization is incomplete for these containment times. As the magnetic field at the entrance cusp is increased, the injected plasma stream is focused; however, the β of the plasma decreases. Both of these effects smear out any manifestation of a critical magnetic field. Problems that arise in achieving a high β region for higher input velocities are discussed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. L. Tuck, Phys. Rev. Letters 3, 313 (1959)

H4. Current Distribution and Stability Measurements on a Coaxial Plasma Gun.* L. C. BURKHARDT AND R. H. LOVBERG, *Los Alamos Scientific Laboratory.*—The distribution of current and the formation of instabilities in the accelerating sheath in a coaxial plasma gun[1] have been investigated by the use of magnetic probes. Under certain conditions of initial gas distribution and applied voltage, the current is found to flow radially in a layer thin compared to the gun diameter. The acceleration of this sheath corresponds to an efficient sweeping of the gas it encounters. At a time dependent on sheath mass loading, the current distribution becomes unstable and loses its azimuthal symmetry, gathering into a pinched discharge at one side of the tube. Dependence of maximum plasma velocity on voltage and sheath mass will be shown to correspond to the simplest interpretation of sheath dynamics.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. Marshall, Phys. Fluid 3, 134 (1960).

H5. Acceleration and Confinement of Ionized Gases by Plasma Waves.* THOMAS H. STIX, *Princeton University.*—Waves moving through a plasma tend to carry along those charged particles which are moving with approximately the wave velocity. The force on the particles may be found by integrating $(\mathbf{E})^{(1)}+\mathbf{w}\times\mathbf{B}^{(1)}f^{(1)}$ over the velocity distribution, where $f^{(1)}$ is the solution to the collisionless Boltzmann equation which is linear in the first-order quantities $\mathbf{E}^{(1)}$ and $\mathbf{B}^{(1)}$. For isotropic temperature, small Larmor radii, for a static magnetic field in the z direction, and for a wave traveling in the z direction with the mean one-dimensional thermal velocity for particles, the time-averaged force on the particles is $0.030\beta k(B_z^{(1)})^2+0.030(k\lambda_D)^{-2}k(E_z^{(1)})^2$ per unit volume, where β is the ratio of particle pressure to static magnetic pressure, k is the wave number in the z direction, λ_D is the Debye wavelength, and $B_z^{(1)}$ and $E_z^{(1)}$ denote maximum field amplitudes. If the force is applied originally to the electrons, electric fields in the plasma arise that transmit essentially the entire force to the ions. The force may be used to confine plasmas or to accelerate plasmas for injection or propulsion. A promising example occurs with the creation of the traveling wave by magnetic induction at a frequency in the neighborhood of the geometric mean of the ion and electron cyclotron frequencies.

* Supported by the U. S. Atomic Energy Commission.

H6. Confinement and Acceleration of Plasmas by A. C. Fields. T. W. JOHNSTON, *RCA Victor Research Laboratories.*—The considerable interest in plasma confinement and acceleration has led to investigation of time-averaged effects of ac fields. Without a clear understanding of the basic particle motions, crucial errors are easy to make. Consideration of the single-particle or charge blob model and the two-particle or two-blob model lead to some basic results. For the case $E\perp\nabla E^2$, the gradient field (∇E^2) mechanism always tends to drive the plasma to field minima. For low field frequencies ($\omega_p^2\gg\omega^2$) the effect is a somewhat porous radiation pressure. The material is nearly all confined when $\omega_p^2\gg\omega^2$ (consistent with the fact that radiation pressure does not vary with frequency), but the small leak rate is reduced by lowering ω to increase the confinement time. The effect of an external dc magnetic field is also considered. For $E\|\nabla E^2$, only frequencies above ω_p lead to acceleration toward field minima. For low frequencies ($\omega<\omega_p$) the drift is toward field maxima—the familiar phenomena of dielectrophoresis. Since most useful systems operate with $\omega_p^2\gg\omega^2$, the field configuration must be such that $E\cdot\nabla n=0$ everywhere; otherwise, in the regions where $E\cdot\nabla n\neq0$, a component of the field will act to disperse the plasma.

H7. Plasma Acceleration in an rf Field Gradient—Theory.* G. D. GORDON, *RCA Astro-Electronic Products Division.*—The velocity change of a plasma moving through an rf field gradient has been calculated on the basis of energy considerations. A fully ionized plasma, of constant density ρ, is assumed to form a thin slab perpendicular to the rf electric field E. The plasma is assumed to move adiabatically from a high rf field region to one of zero field. It attains a final velocity v_f of

$$v_f=\left\{v_i^2+\frac{\omega_p^2\epsilon_0E^2}{2\rho}\left(\frac{\omega^2-\omega_p^2}{(\omega_p^2-\omega^2)^2+(\omega\nu)^2}\right)\right\}^{\frac{1}{2}},$$

where v_i is its initial velocity, ν the collision frequency, ϵ_0 the permittivity of free space, ω the applied frequency, and ω_p the

plasma frequency. Depending on whether ω is greater or less than ω_p, the final velocity can be greater or less than the initial velocity, in agreement with the detailed calculations of T. W. Johnston.[1] Extensions of the theory to other plasma geometries will be given.

* Supported by ARPA through the U. S. Air Force Office of Scientific Research.

[1] T. W. Johnston (private communication).

H8. Plasma Acceleration in an rf Field Gradient—Experimental.* G. A. SWARTZ AND H. W. LORBER, *RCA Laboratories*, AND T. T. REBOUL, *RCA Astro-Electronic Products Division.*—The plasma acceleration predicted in the previous paper[1] has been observed in the laboratory. A blob of mercury plasma emerges from a small aperture into a 140-Mc rf field which decreases monotonically in space. After the plasma reaches the zero field region, it is detected by a series of wire probes. The plasma velocity is determined from transit time measurements between the aperture and the probes. With a maximum amplitude of the rf field of 170 v/cm, a plasma with a density of about 5×10^8 ions/cm^3 was accelerated from 5×10^5 cm/sec to 25×10^5 cm/sec. For this blob, $\omega_p/2\pi=118$ Mc. When the plasma density was increased to 10^{10} ions/cm^3 ($\omega_p/2\pi=520$ Mc), the plasma was decelerated. These experimental results agree quantitatively with theory. Plasma density fluctuations with a period of 6 μsec have been observed in the accelerated plasma.

* Supported by ARPA through the U. S. Air Force Office of Scientific Research.

[1] G. D. Gordon, preceding abstract.

H9. Optical Observations of Plasmas Accelerated into a Vacuum. PER GLOERSEN AND BERNARD GOROWITZ, *General Electric Space Sciences Laboratory.*—Plasmas were produced and accelerated into a 6-in. glass vacuum chamber by means of a 3-in. diameter coaxial type accelerator, with pulsed gas entry.[1] The chamber was pumped to a pressure of 10^{-6} mm of Hg before firing the accelerator. Nitrogen, argon, and helium were introduced successively into the accelerator in order to produce the plasmas. Observations with a rotating mirror camera indicated velocities of the escaping plasmas as high as 3×10^7 cm/sec. Kerr cell photography and Schlieren techniques were used to examine the expansion of the luminous and nonluminous portions of the plasma, respectively, both parallel and perpendicular to the direction of propagation. The results will be presented and discussed.

[1] B. Gorowitz, K. Moses, and P. Gloersen, Rev. Sci. Instr. 31, 146 (1960).

H10. Plasma Acceleration in a Vacuum. ALAN ANDREW AND JAMES P. FITZPATRICK, *Lockheed Missiles and Space Division.*—The acceleration of a plasma into a vacuum by means of an axially symmetric but noncylindrical discharge tube has been investigated. The discharge tube has an open electrode at one end and a solid electrode at the other. Attached to the latter is a fast-acting eddy current gas valve and connected across both electrodes is a fast capacitor. A pulse of argon gas is admitted to the evacuated discharge tube which then discharges when the proper conditions are met. The current pinches down at the solid electrode and, with the aid of joule heating, forces the plasma out through the open electrode into a vacuum chamber where the plasma velocity and impulse are measured. The impulse and velocity have been measured as a function of the angle subtended by the open electrode at the center of the solid electrode. The effect of the amount of gas admitted by the valve on the impulse and velocity also has been measured.

H11. Analysis of a Coaxial Plasmoid Source. D. M. WETSTONE AND E. C. LARY, *United Aircraft Research Laboratories.*—A coaxial plasmoid source with concentric cylindrical electrodes is examined. A puff of gas is injected into the annular space, across which a capacitor bank is then discharged. The radial current through the plasmoid crosses with the resulting azimuthal magnetic field to produce axial acceleration. This geometry is similar to that of Marshall[1] except that the annular spacing is small (2 mm) compared to the mean radius (19 mm), thus providing approximately spatially uniform acceleration of the toroidal plasmoid and reducing the occurrence of "hot spots" on the center electrode. Also, the gun is fired shortly after gas injection, before the gas has spread appreciably in the axial direction. The analysis is based on the well-known relation: $IR+d(LI)/dt=V(T)$. Here, L includes the inductance contributions of the entire circuit, $V(t)$ is the potential of a noncrowbarred capacitor bank, $dL/dt=v(dL/dz)$, with v the plasmoid velocity, and R includes the (time-dependent) total resistance of the external circuit and the Joule-heating resistance of the plasmoid. The results obtained from analog computation are presented. Experiments employing this geometry are currently in progress.

[1] John Marshall, Phys. Fluids 3, 137 (1960).

H12. Criteria for Interaction of an Expanding Plasma with a Weak External Field. I.* L. N. ZADOFF AND M. BERNSTEIN, *Republic Aviation Corporation.*—Although a blob of plasma injected into a magnetic field initially may have a high enough conductivity for transport of the magnetic field to dominate diffusion, the initial expansion is accompanied by a fall in temperature. This is the result of conversion of internal energy to kinetic energy. Ultimately, if transport continues to dominate, the deceleration of the expanding plasma will be accompanied by a rise in temperature. If, however, the temperature drops too far during the initial expansion, the accompanying fall in conductivity will permit diffusion across the field to dominate. A model for calculation of the dynamics of a symmetrical expansion is developed. When the initial volume is much less than a critical volume, the expansion initially may be closely described by the equations of plasma motion in a field-free vacuum. These equations are integrated permitting a calculation of the temperature as a function of the blob radius.

* This work was supported by the U. S. Air Force Special Weapons Center.

H13. Criteria for Interaction of an Expanding Plasma with a Weak External Field. II.* M. BERNSTEIN AND L. N. ZADOFF, *Republic Aviation Corporation.*—If one has available the temperature of a plasma as a function of the radius in a free expansion, he may calculate the degree of ionization resulting from two-body radiative recombination processes. It is found that, for volumes large compared to the initial volume, the degree of ionization becomes independent of the volume. This is to be expected on physical grounds since the rate of recombination goes to zero for large volumes. The magnetic Reynold's number also may be calculated and is found to be dependent on the radius during the early part of the expansion. If the magnetic Reynold's number becomes much less than unity while the radius of the plasma is still small, the expansion will be unaffected by the presence of the magnetic field until the particle density becomes so low that magnetohydrodynamic approximations have no meaning.

* This work was supported by the U. S. Air Force Special Weapons Center.

H14. End Effects in dc Electromagnetic Pumps or Generators. G. W. SUTTON, H. HURWITZ, JR., AND H. PORITSKY, *General Electric Company.*—Consideration is given to steady, dc electromagnetic pumps for electrically conducting inviscid incompressible fluids and to steady dc magnetohydrodynamic generators. The geometry is a channel with a rec-

tangular cross section; two sides of the channel are the pole faces of the magnetic field, and the other two sides are electrodes which are in intimate contact with the fluid. In the region exterior to the magnetic field, electric currents will flow from the high potential side of the channel to the low potential side which reduces the efficiency of the device. The end losses are calculated by means of conformal mapping of the potential function. Calculations are presented which show that these losses are reduced by shading the magnetic field in the upstream and downstream direction. Flux plots are also presented for the case of tensor electrical conductivity for the case where the conductivity is zero in the region exterior to the electrode region and the case where the magnetic field extends infinitely upstream and downstream also is considered.

THURSDAY MORNING AT 9:30

McConnell Engineering Building 304

(M. N. ROSENBLUTH presiding)

Plasma Physics, III

J1. Surface Instability Growth Rates.* W. E. DRUMMOND AND M. N. ROSENBLUTH, *General Atomic.*†—For a pinch with a distributed current distribution the differential equation for marginal stability has singular points. If the current is confined to a thin surface layer, the stability criteria can be analytically obtained[1] and are difficult to satisfy with realizable field configurations. However, for unstable situations the inclusion of the growth rate removes the singular point, and for thin current layers the growth rate is shown to be proportional to the layer thickness. Numerical results for several field configurations will be presented.

* Research on controlled thermonuclear reactions is a joint program carried out by General Atomic and the Texas Atomic Energy Research Foundation.

† John Jay Hopkins Laboratory for Pure and Applied Science, General Atomic Division of General Dynamics Corporation, San Diego, California.

[1] M. N. Rosenbluth, "Stability and heating in the pinch effect," in *Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy* (United Nations, Geneva, 1958), Vol. 31, p. 85.

J2. Instability Waves in Magnetically Confined Plasmas. A. A. WARE,* *A.E.I. Research Laboratory, Aldermaston* (introduced by D. W. Kerst).—Previous theoretical treatments of hydromagnetic instability have obtained normal mode solutions of the form $A(\mathbf{r})\exp(i\omega t)$, where ω^2 is always real, so that when the plasma is unstable ($\omega^2<0$) there is no wave motion. However, past experimental measurements of instability motion have shown it to be a wave motion. In this paper it is pointed out that the Hall emf should be retained in the electric conduction equation, in which case the magnetic field behaves approximately as if it is trapped to the mean electron velocity and not to the mass velocity. An instability configuration therefore is carried along with the mean electron velocity, and for the positive ions it is a wave motion. Such waves are markedly different from previous types of hydromagnetic waves, and theory predicts the correct sign and magnitude of the observed wave velocity and also its variation with magnetic field and pressure.

* A. A. Ware is at present on leave of absence at General Dynamics Corporation's General Atomic Division, San Diego, California.

J3. Experimental Observation of Instability Waves in Sceptres III and IV. N. L. ALLEN, A. A. WARE,* AND R. V. WILLIAMS, *A.E.I. Research Laboratory, Aldermaston* (introduced by D. W. Kerst).—A recent theory predicting that hydromagnetic instabilities should propagate as waves is in good agreement with the waves reported by earlier workers for fairly low current ($\gtrsim 10^4$ amp) pinch discharges. Since the large amplitude effects expected for such waves explain most of the previously unexplained properties of the high current toroidal pinch discharges, such as Sceptres III and IV, experiments were carried out on these discharges to obtain direct evidence for these waves. Magnetic probes and a photomultiplier-monochromator were used, and two such waves were found to be present simultaneously. In the central core of the discharge there is a wave moving anti-parallel to the current, and in the outer regions another wave moves in the opposite direction. These observations are found to be in agreement with the theory when the unusual pressure distribution in these dicharges is taken into account.

* A. A. Ware is at present on leave of absence at General Dynamics Corporation's General Atomic Division, San Diego, California.

J4. Hydromagnetic Stability of Force-Free Toroidal Fields.* JOHN L. JOHNSON,† *Princeton University.*—It is shown that stellarators can be made hydromagnetically stable during the ohmic heating phase of their operation when the pressure is zero—namely, for force-free systems ($p=0$) curvature does not affect the stability criteria which were obtained[1] for a large class of equilibria in which small multipolar fields and axial currents distort a zero-pressure plasma in a uniform axial magnetic field. The effect of curvature is introduced by working in a noncylindrical coordinate system. It has been shown[2] that solutions with zeroth-order magnetic surfaces which are functions of r alone can be found if, and only if, the system is force-free with no externally imposed transverse fields. For this class of equilibria the curvature of the system drops out of the calculation when an energy principle is used to determine the stability. Therefore, the demonstration[1] that multipolar fields can eliminate "kink" instabilities is applicable to force-free toroidal systems.

* This work was supported under contract with the U. S. Atomic Energy Commission.

† On loan from Westinghouse Electric Corporation, Atomic Power Department.

[1] J. L. Johnson, C. R. Oberman, R. M. Kulsrud, and E. A. Frieman, Phys. Fluids 1, 281 (1958).

[2] J. M. Greene and J. L. Johnson, Bull. Am. Phys. Soc. Ser. II, 5, 312 (1960).

J5. Sensitivity of Magnetic Lines to Errors in Stellarators.* D. W. KERST, *General Atomic.*†—The rotational transform for lines of force guiding plasma around a torus containing a circumferential field plus a twisted multipole field has "stability" limits for the vacuum field lines at large aperture, that is, lines of force outside this limit leave the aperture. The sensitivity of the size of this limit to periodically applied field errors has been numerically examined as a function of the increasing magnitude of the error. Decrease in aperture with increasing magnitude of error is observed just as it is in the topologically analogous case for phase space plots of alternating gradient particle accelerators with nonlinear forces.[1] For example, the stable aperture of a six-pole ($l=3$) transform

winding suffers a several fold decrease in area if a transverse field error of 20% of the multipole (not circumferential) field is applied for 10% of the circumference of the torus.

* Research on controlled thermonuclear reactions is a joint program carried out by General Atomic and the Texas Atomic Energy Research Foundation.
† John Jay Hopkins Laboratory for Pure and Applied Science, General Atomic Division of General Dynamics Corporation, San Diego, California.
[1] D. W. Kerst, Bull. Am. Phys. Soc. Ser. II, **4**, 352 (1959).

J6. Experimental Observation of a Velocity-Space Plasma Instability.* W. A. PERKINS AND R. F. POST, *Lawrence Radiation Laboratory, Livermore.*—A hydrogen plasma is injected, captured, and heated in a Mirror Machine[1] by adiabatic magnetic compression, producing a plasma with a high electron temperature.[1,2] Escaping plasma electrons are monitored by scintillators, one at the midplane protruding into the vacuum system. At peak compression (500 μsec), the midplane field is 10 kgauss; compression ratio is controlled by the initial field. At sufficiently low initial fields, strong signals can be detected by the midplane scintillator at any position between 1 in. from the axis and the vacuum chamber wall, indicating enhanced transport of electrons across the magnetic field. As the initial field is increased slightly, these signals abruptly drop below the limit of detectability. The enhanced diffusion also can be eliminated either by substantially decreasing *or* increasing the trapped plasma density. These data are interpreted as the direct experimental evidence of a particular plasma instability, previously predicted theoretically to occur in highly anisotropic confined plasmas, and here produced by the compression process itself, as discussed in the paper following.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] R. F. Post, *Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy* (United Nations, Geneva, 1958), Vol. 32, p. 245.
[2] R. F. Post, R. E. Ellis, F. C. Ford, and M. N. Rosenbluth, Phys. Rev. Letters **4**, 166 (1960).

J7. Velocity-Space Plasma Instabilities Observed in a Mirror Machine—Theory and Interpretation.* R. F. POST AND W. A. PERKINS, *Lawrence Radiation Laboratory, Livermore.*—Results described in the previous paper are compared with hydromagnetic stability theory, which predicts plasma instability, even at relatively low plasma densities, for anisotropic, magnetically confined plasmas where the plasma pressure ratio $p_\perp/p_\parallel \gg 1$.[1,2] These instabilities are predicted to occur above a critical value of $\beta = p_\perp/(B^2/8\pi)$ which is given approximately by $\beta_c = (p_\perp/p_\parallel)^{-1}$ in simple cases. In a Mirror Machine, highly anisotropic plasma distributions can be produced by adiabatic magnetic compression (which primarily increases $p_\perp$), provided the ratio of final to initial field is large and collisional randomization is unimportant. Thus, if the density of the plasma to be compressed lies above a certain minimum value, dependent on the compression ratio, yet at the same time lies below densities where collisional effects are important, a plasma instability induced by the compression process is predicted. The conditions required to produce such instabilities, and their parametric variations, are calculated theoretically and compared with the experimental results given in the previous paper. Their possible relevance to other plasma confinement studies is also indicated.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] S. Chandrasekhar, A. Kaufman, and K. Watson, Proc. Roy. Soc. (London) **A245**, 435 (1958).
[2] W. Newcomb, Ann. Phys. (to be published).

J8. Nonlinear Plasma Oscillations.* E. ATLEE JACKSON, *Princeton University.*—The general solution of the Eulerian equations for the cold, one-dimensional plasma is obtained in closed form. The relationship between this solution and the known Lagrangian solution of the same physical problem[1] is exhibited. The nonlinear oscillations have the same period ω_p^{-1} as the linear oscillations. Because of the parabolic nature of these equations, one also can apply a perturbation technique which has been used extensively by Kryloff and Bogoliubov.[2] This perturbation method does not yield any frequency shift, in contrast to Sturrock's results,[3] and agrees in detail with the exact solution. For higher dimensional oscillations it is known from the Lagrangian analysis of Dawson[1] that the Eulerian equations generally break down after a finite time and, consequently, are of limited interest.

* This work was supported under contract with the U. S. Atomic Energy Commission.
[1] J. Dawson, Phys. Rev. **113**, 383 (1959).
[2] N. Kryloff and N. Bogoliubov, *Introduction to Nonlinear Mechanics* (Princeton University Press, Princeton, New Jersey, 1947).
[3] P. A. Sturrock, Proc. Roy. Soc. (London) **A242**, 277 (1957).

J9. A One-Dimensional Plasma Model. JOHN DAWSON, *Princeton University.*—A plasma consisting of a large number of identical sheets of charge embedded in a uniform fixed neutralizing background is investigated. The sheets are constrained to be parallel and to move only in the direction of their normal. They are allowed to pass freely through each other. This model exhibits a number of real plasma properties; it has both collective and individual particle motions and each sheet is surrounded by a Debye shielding cloud. The Fourier modes show Landau damping. Systems containing up to 1000 sheets were followed in detail on the NYU 704 computer. Such quantities as the Debye shielding distance, the drag on supersonic and subsonic sheets, the probability that sheets will feel an electric field E, the probability that a Fourier mode will have an amplitude A, the average potential energy of a Fourier mode, the dispersion relation relating ω and k for the Fourier modes, and the Landau damping of the Fourier modes were obtained from these calculations. These results were compared with theoretically predicted values and were found to be in excellent agreement.

J10. Magnetic Compression Waves in a Collision-Free Plasma. R. W. KILB AND P. L. AUER, *General Electric Research Laboratory.*—Numerical calculations previously reported[1,2] have been extended using a boundary condition in which the electric field is held constant at a stationary surface. The plasma motion in one dimension is simulated by a set of discrete current sheets, and orbit crossings are treated in detail. The major features observed are independent of mesh size. Situations in which the initial magnetic field is either parallel or antiparallel to the external imploding field are studied. It is found that the magnetic disturbance propagates into the plasma as a front, leaving a wake of waves behind. The amplitude of these waves decreases with distance from the front. Turbulence as evidenced by orbit crossings decays spatially to either side of the leading edge, disappearing completely whenever the local Alfven-Mach number becomes less than two. Very large amplitude disturbances are accompanied by field reversal and large-scale turbulence. Magnetic wave interactions have been studied by following repeated reflections from a plane of symmetry.

[1] J. H. Adlam and J. E. Allen, *Proceedings of the Second United Nations Conference on the Peaceful Uses of Atomic Energy* (United Nations, Geneva, 1958), Vol. 31, p. 221.
[2] J. H. Adlam and I. C. Pyle, AERE-R3002 (1959).

J11. Shock Relations in Magnetic Compression Waves. P. L. AUER AND H. HURWITZ, JR., *General Electric Research Laboratory.*—In the calculations described above the disturbance front velocity, the plasma-vacuum interface velocity, and the vacuum magnetic field agree closely with elementary shock theory for a perfectly conducting gas with a specific heat ratio of two. The wave distribution in the disturbed region is, however, not uniform but is instead related to Gardner's linearized wave train[1] which diffuses in time as $t^{\frac{1}{2}}$. The leading portion of the disturbance in regions devoid of orbit crossings

conforms to stationary solutions previously given[2] with the asymptotic decay $\exp[-(1-1/M^2)^{\frac{1}{2}}\xi]$, where M is the Mach number and ξ is the Lagrange coordinate. It is proposed that in many cases of interest the major dissipative mechanism is electrostatic instability arising from the electron flow in the plane of the disturbance front. The corresponding shock thickness is then comparable to the electron gyration radius.

[1] C. S. Gardner, *et al.*, *Proceedings of the Second United Nations Conference on the Peaceful Uses of Atomic Energy* (United Nations, Geneva, 1958), Vol. 31, p. 230.
[2] J. H. Adlam and J. E. Allen, Phil. Mag. 3, 448 (1958).

THURSDAY MORNING AT 10:00

Physical Sciences Auditorium

(V. F. WEISSKOPF presiding)

Invited Papers Mostly in Nuclear Physics

JA1. Low-Energy Neutron Spectroscopy and the Optical Model. K. K. SETH, *Duke University.* (30 min.)

JA2. Time-of-Flight Photoneutron Spectroscopy with an Electron Linear Accelerator. P. T. DEMOS, *Massachusetts Institute of Technology.* (30 min.)

JA3. Correlation Functions and Momentum Distributions in Nuclei. KURT GOTTFRIED, *Harvard University.* (30 min.)

JA4. Electron Structure of Solids by Positron Annihilation. A. T. STEWART, *Dalhousie University.* (30 min.)

THURSDAY MORNING AT 9:45

Chemistry Amphitheatre

(P. LORRAIN presiding)

Apparatus of Nuclear Physics

K1. Ten-Mev Linear Accelerator. J. E. CRAWFORD, J. S. FOSTER, AND W. M. TELFORD, *McGill University.*—The McGill Radiation Laboratory has been constructing a linear accelerator for electrons, installed in the Radiology Department of the Royal Victoria Hospital in Montreal. This accelerator is a conventional traveling wave type, employing a disk-loaded circular waveguide. Four mw of rf power, to accelerate the electrons, is provided by a high-power *S* band magnetron operating at 2800.0 Mc. Electrons are injected from a modified Pierce gun into the accelerator input, bunched and accelerated to 1 Mev in the first 2 ft, and accelerated to 10 Mev in the remaining 6 ft. Preliminary tests have given an electron beam of 10 Mev with radiation intensity greater than 2000 r/min at 1 m from the end. The steering magnet and x-ray head, as well as a medical mounting, remain to be completed. The accelerator will be used mainly for cancer therapy: it is hoped there will be slack periods when it may be applied to research in physics and biophysics.

K2. High Current Pulsed Electron Accelerator.* N. C. CHRISTOFILOS, *Lawrence Radiation Laboratory, Livermore.*—An induction type accelerator for the acceleration of high current electron beams in the Mev range has been developed in connection with the Astron program. A peak current of 200 amp is necessary to meet the requirements of the proposed Astron injection and trapping method. Microwave accelerators are limited to much lower currents. The proposed accelerator resembles a pulse transformer with one turn secondary. The accelerating field is generated along the symmetry axis of a large number of identical cavities loaded with ring-shaped ferromagnetic cores. The cavities enclose an accelerating column built with ceramic and metallic rings. The electric field is generated between the metallic rings. The solution of the field equations in the volume enclosed by the accelerating column yields:

$$E_z = E_0[1 + \Sigma_n a_n b_n I_0(nkz)\cos(nkz)].$$

By proper choice of the geometrical parameters the higher harmonics are suppressed in the region of the electron beam near the axis of symmetry. Parameters of the 200-amp Astron accelerator now under construction will be presented.

*Work performed under the auspices of the U. S. Atomic Energy Commission.

K3. New Semiconductor Nuclear Particle Detector. R. L. WILLIAMS, *RCA Victor Research Laboratories, Montreal* (introduced by R. J. McIntyre).—By using high-resistivity silicon, a nuclear particle detector of transistor configuration has been constructed. The depletion layer of the collector junction can be extended to the emitter junction by the application of the appropriate bias. Base widths can be made sufficiently narrow to give current multiplication factors from 300 to 1500. An increase in signal to noise is predicted over that of a single *p-n* junction detector which is proportional to the square root of the multiplication factor. The device can be used as an alpha-particle detector and a large area phototransistor. The variation of noise, signal level, and impedance with bias will be reported.

K4. Performance of *p-n* Junction Particle Detectors under Gamma Irradiation.* C. T. RAYMO, J. W. MAYER, J. S. WIGGINS AND S. S. FRIEDLAND, *Hughes Aircrfat Company.*—Shallow-diffused silicon *p-n* junctions have been used previously to measure the energy spectrum of fission fragments.[1]

In order to determine the feasibility of using these devices as neutron detectors, the noise level and resolution were measured under gamma irradiation. In a gamma flux of 4×10^5 r/hr, the noise level of 300 Ωcm 2×2 mm detectors increased to an equivalent noise level of 2.3 Mev with a subsequent deterioration of resolution for 4.5-Mev alpha particles from 1% to 25%. With units of higher base resistivity and/or larger surface area, the equivalent noise level increased. For example 10^4 Ωcm 5×5-mm units had an equivalent noise level of 20 Mev. These effects could not be attributed solely to the increased dc current but are apparently caused in part by "pile-up" effects in the detector of pulses caused by gamma-generated Compton electrons. The results indicate that low resistivity devices are useful as fission fragment and/or neutron detectors in high gamma fluxes, but their application as spectrometers is restricted. Under lower fluxes, the detrimental effects of the gammas are reduced.

* This work supported in part by the Defense Atomic Support Agency.
[1] S. S. Friedland, J. W. Mayer, and J. S. Wiggins, Nucleonics **18**, 54 (1960).

K5. Performance of Large Area *p-n* Junction Particle Spectrometers.* J. W. MAYER, R. J. GRAINGER, J. W. OLIVER, J. S. WIGGINS, AND S. S. FRIEDLAND, *Hughes Aircraft Company.*—The performance of small area shallow diffused silicon *p-n* junctions has been reported previously,[1] but the feasibility of large area diffused devices has remained in question. Recently 10^4 ohm-cm devices 5×5 mm in area, and larger, have been made with a resolution of less than 1% for 6-Mev alpha particles. The response of the large devices to alpha particles, fission fragments, protons, and electrons will be shown. Studies of the width of the pulse height distribution as related to the noise level and reverse current will be presented and the question considered whether the major component of the current is contributed by carriers generated in the space-charge region. Deterioration of the performance of the detectors at elevated temperatures will be indicated.

* This work supported in part by the Defense Atomic Support Agency.
[1] S. S. Friedland, J. W. Mayer, and J. S. Wiggins, Nucleonics **18**, 54 (1960).

K6. Application of Thick-Depletion-Layer Silicon *p-n* Junctions to Proportional Detection of Gamma Radiation and Penetrating Nuclear Particles.* PAUL F. DONOVAN, *Bell Telephone Laboratories,* G. L. MILLER, *Bell Telephone Laboratories and Brookhaven National Laboratory,* AND BRUCE M. FOREMAN, JR., *Brookhaven National Laboratory.*—Silicon *p-n* junction particle detectors have been prepared which have depletion layers about 0.8 mm thick. Conversion electrons and gamma rays which give photoelectrons with ranges less than this distance have been detected with good energy resolution. The gamma-ray line widths are about 6.5 kev. This width appears to be limited by electronic noise. These counters also have been used to detect cylotron-produced helium ions up to 40 Mev and protons up to 12 Mev. The pulse heights were proportional to the particle energy, and the energy resolution was apparently limited by the cyclotron beam spread. Proton- and alpha-particle groups with energies up to about 12.5 Mev were observed with good linearity and energy resolution from the reactions $B^{10}(d,p)B^{11}$ and $B^{10}(d,\alpha)Be_8$ with 1.5-Mev incident deuterons. Resolution appears to have been limited by target thickness and angular spread to about 70 kev. Elastic scattering experiments with helium ions and protons at energies up to 3 Mev gave line widths as low as 20 kev. Minimum ionizing particles have been detected with good signal-to-noise ratio.

* This work was supported in part by the U. S. Atomic Energy Commission.

K7. Silicon *p-n* Junctions as Particle Spectrometers. J. M. MCKENZIE, *Chalk River Laboratories.*—Both *p-n* diffused junctions and Au-Si surface barriers are satisfactory room-temperature particle spectrometers. Recent studies, however, have been confined to the diffused junction. The yield of good junctions is much higher for the *p-n* than for the Au-Si type. The sensitive thickness of the detector can be controlled by choosing silicon of the appropriate resistivity and operating the detector at a suitable bias voltage. This enables a junction to be made which will permit heavy ionizing particles such as oxygen ions which stop in the junction to be detected in the presence of the same energy protons or alpha particles: the thickness of the junction is adjusted to be less than the range of the latter particles. A resolution of 16 kev (width at ½ maximum) for 6.04-Mev alpha particles is obtained with a junction of sufficient thickness to stop 10-Mev alpha particles. The two well-known beta lines at 115 and 129 kev from Co^{57} have been resolved using a junction made from 12 000-ohm-cm silicon. Radiation damage to the detectors will be discussed.

K8. Binary Compound Surface Junction Counters. ARTHUR BRAMLEY,* *Bramley Consultants.*—Different structures are evaluated for room-temperature ionizing particle detectors, which require a thin surface barrier with high rectification ratio. In Au-Si surface barriers and P diffused $(n+)$-high resistivity p-type Si junctions with the same material throughout the junction but activation varied throughout the interelectrode region, the type of carriers injected across this region is determined by activation. With a narrow insulator separating two layers of the same semiconductor, injection occurs by majority carriers tunneling through the insulator. By using CdS as the semiconductor on opposite sides of an ionic insulator 10 A thick, Van Santen and Diemer achieve a high rectification ratio by forming a built-in space charge of ions in the insulator. In another variation,[1] activation, giving degenerate p-type Si on one side of a layer with a metallic electrode on the other, produces maximum energy difference between the bottom of conduction bands on opposite sides of the insulator. This was expected to give high rectification ratio at low voltages.[2]

* Now at Republic Aviation.
[1] C. A. Mead, Proc. Inst. Radio Engrs. **48**, 359 (1960).
[2] A. Bramley and J. E. Rosenthal, Symposium, Brooklyn Polytech Institute (April, 1957).

K9. Pulse Height Distribution of Čerenkov Counters. RICHARD J. WAGNER, *Space Technology Laboratories, Inc.*—The pulse height distribution (PHD) of path length-dependent radiation counters (i.e., detectors in which the output pulse is a function of the distance traveled by the particle in the counter) has been studied theoretically in order to predict the effect on the PHD of distributions in charge, velocity, and mass of the incident radiation when a distribution of geometrical path lengths in the counter is available to the particles; the effect of the finite range of the particles in the medium is also considered. Calculated Čerenkov PHD's for some special cases of interest will be presented. The limitations of the equations and their applicability to other counters will be discussed.

K10. Fast Counting of Alpha Particles in an Air Ionization Chamber. Z. BAY, F. D. MCLERNON, AND P. A. NEWMAN, *National Bureau of Standards.*—It was assumed in the past that counting of alpha particles in air ionization chambers could be based only on the collection of ions since electrons produced in the alpha track quickly form negative ions in electronegative gases. This leads to time resolutions of the order of 1 msec. It is shown in the present work that the motion of the electrons before attachment produces a sharp initial rise in the pulse profile which, although small, can be detected and utilized for high-speed counting. Time resolutions of the order of a few microseconds with good signal-to-noise

ratios are realized in atmospheric air, and therefore counting speeds similar to those in nonelectronegative gases are obtained.

K11. Iron-Free Toroidal Beta-Beta Coincidence Spectrometer.* MELVIN S. FREEDMAN, FRANK WAGNER, JR., JOHN TERANDY, FREDERICK T. PORTER, PAUL P. DAY, AND CARLOS A. MALLMANN, *Argonne National Laboratory.*—Two identical opposed 100-turn toroidal windings of 1-m diam focus β's emitted between 30°-70° of their axis. Conductors bounding field entrance and exit are identical, consistent with parameter $b=\rho/r=0.59$. $E_{max}=3.5$ Mev, requiring 1150 amp at 140 kw with 10°C rise. Performance results on first unit: (trans. T, % of 4π, *measured*; resolution R, full width at half max); $\frac{1}{8}$-in. *source*, $T=19\%$, $R=1.0\%$; $T=16\%$, $R=0.40\%$; $T=2.8\%$, $R=0.21\%$; $\frac{1}{4}$-in. *source*, $T=15\%$, $R=1\%$; 1-mm *source*, $T=16\%$, $R=0.2\%$. Efficiency for coincidence studies at $R\leq 1\%$ is thus improved by >100. The leakage field at the source and in other spectrometers $\leq 10^{-6}$ of the focusing field; thus 1-kev and 3-Mev betas focus with negligible interference. A special nonferrous building enables degaussing $H_{earth}\approx 10^{-4}$ oe. Facilities are provided for $\alpha,e-$ (α's analyzed in ion chamber) and β,γ coincidences ($\leq$3-in. NaI crystal near source) and β,γ and β,β angular correlation studies over range 45°–180° with $T=1\%$. Operation and recording are automatized.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

K12. Note on Evaluating Delayed Coincidence Experiments. R. S. WEAVER AND R. E. BELL, *McGill University.*—Frequently in delayed coincidence work a resolution curve is measured with good accuracy, but no exactly comparable prompt resolution curve is available. The centroid-shift method of evaluating the lifetime τ cannot be applied because the zero of time (centroid of the prompt curve) is not known. If τ is close to the instrumental limit, it cannot be measured from the logarithmic slope of the measured resolution curve. We then require an objective measure of the asymmetry of the measured curve, calculable without reference to any other curve. Such a quantity is the third moment of the measured curve about its own centroid. We show that this third moment is equal to $(2\tau^3+\epsilon)$, where ϵ is the third moment of the prompt curve, usually small and frequently negligible. Thus τ can be evaluated with at most only rough knowledge of the prompt curve. The McGill IBM 650 computer has been programed to perform the arithmetical work, which is otherwise laborious. An application to an actual example is shown. Estimates are given of the accuracy to be expected from the method.

K13. Six-Meter Radius Bent-Quartz Crystal Spectrograph.* A. H. KAZI, N. C. RASMUSSEN, AND HANS MARK, *Massachusetts Institute of Technology.*—A 6-m radius, Cauchois geometry bent-crystal spectrograph has been constructed at the MIT Nuclear Reactor for the study of neutron capture gamma rays. The sample is placed in the through-tube next to the reactor core. The crystal is mounted near the face of the reactor shield, and the gamma-ray lines are recorded on glass-mounted Ilford G-5 nuclear emulsions placed on the focal circle of the instrument. The quartz crystals used in this instrument are 0.4 cm thick and have linear dimensions of 4 in.×5 in. The (3.10) planes are used to diffract the gamma rays. Annihilation radiation (0.511 Mev) lines are observed to have a line width of about 0.320 mm which means that it will be possible to determine the energies of gamma rays in the Mev region to 0.1%. For gamma rays in the 1-Mev region a source strength of over 10^3 curies is necessary to keep exposure times below 100 hr.

* Supported by the National Science Foundation.

THURSDAY MORNING AT 9:45

Engineering Building 204

(D. K. C. MACDONALD presiding)

Magnetism and Cryogenics

L1. Measurements of Magnetic Susceptibility in High Pulsed Magnetic Fields.* RICHARD STEVENSON, *McGill University.*—A technique has been developed for making Gouy type measurements of magnetic susceptibility in pulsed magnetic fields of up to 600 000-oe intensity. By use of this method, susceptibility measurements have been made on a number of salts of iron group elements. Changes in susceptibility at high fields have been observed in at least two substances, $MnSO_4$ and $MnCO_3$. The changes observed in these substances may be due to a paramagnetic-antiferromagnetic transition caused by the external field.

* Supported in part by the Office of Naval Research (U.S.A.) and the Defence Research Board (Canada).

L2. Faraday Rotation and Some Magnetic Properties of Evaporated Thin Films of Iron, Nickel, and Gadolinium.* J. R. HOLMES AND F. J. MCCLUNG, JR.,† *University of Southern California.*—Thin films of iron, nickel, cobalt, and gadolinium have been evaporated, and measurements have been made in the same vacuum system without exposing the films to air. The rotation measurements for iron, nickel, and cobalt will be reported. The films were deposited on glass for the rotation measurements and on carbon for the diffraction studies which also were made. Thickness measurements were made using the Tolansky method. The gadolinium films which were prepared did not show any rotation at temperatures as low as 77°K. These films usually were unstable in the vacuum system unless the film was very thick. Resistance measurements show a large and rapid increase in resistance while still at a pressure of 10^{-6} mm Hg.

* This work supported in part by the National Science Foundation.
† Now at Hughes Aircraft Company, Research Laboratories.

L3. General Spin-Wave Dispersion Relations. R. F. SOOHOO, *Lincoln Laboratory,** *MIT.*—The general spin-wave dispersion relations obtained by a simultaneous solution of Maxwell's equations and the equation of motion of the magnetization are given. In this calculation, the effects of conductivity, propagation, and exchange are properly taken into account. The special conditions under which our general result will lead to the Kittel-Herring dispersion relation are discussed.[1] The question of the compatibility of the requirement of Maxwell's equations and the equation of motion of the magnetization are examined. We found that, whereas

the requirements of these two equations are always compatible for spin-waves, they are compatible for the spatial nonvarying mode only under very special conditions. It appears that only when the permeability of one of the normal modes in a gyromagnetic medium is equal to zero or perhaps in the static limit can the uniform mode simultaneously satisfy both Maxwell's equations and the equation of motion of the magnetization.

* Operated with support from the U. S. Army, Navy, and Air Force.
[1] C. Herring and C. Kittel, Phys. Rev. 81, 869–880 (1951).

L4. Antiferromagnetic Ordering in $FeCo_3$.* S. J. PICKART, *U. S. Naval Ordnance Laboratory and Brookhaven National Laboratory.*—Neutron diffraction data taken on a powder sample of synthetic siderite ($FeCO_3$) have confirmed the antiferromagnetism suggested by the susceptibility measurements of Bizette and Tsai.[1] The crystal structure of this compound is isomorphous with calcite and may be visualized as a NaCl type lattice contracted along a body diagonal. The resulting structure has rhombohedral symmetry (space group $R\bar{3}C$) and consists of layers of cations and layers of complex $(CO_3)^{2-}$ ions stacked in sequence along the [111] direction. The nuclear intensities are in good agreement with the reported oxygen parameter[2] of 0.27, corresponding to a C-O bond distance of 1.26 A. Below the transition temperature (about 20°K on this sample) additional coherent reflections appear that are characteristic of an antiferromagnetic ordering. The Fe^{2+} moments on a given cation layer are parallel and point along the trigonal axis, while neighboring layers are antiparallel. The magnetic structure is thus reminiscent of that found in FeO, although the superexchange interactions in this case are dissimilar. A g factor of 2.5 ± 0.15, derived from the observed magnetic scattering amplitude, suggests that the orbital angular momentum of the Fe^{2+} ion is incompletely quenched.

* Carried out under the auspices of the U. S. Atomic Energy Commission and the National Security Agency.
[1] Cited by H. Bizette, J. phys. radium 12, 161 (1951).
[2] R. Wyckoff, *Crystal Structures* (Interscience Publishers, New York, 1948), Vol. I.

L5. Oblique-Incidence Anisotropy in Evaporated Permalloy Films. D. O. SMITH, M. S. COHEN, AND G. P. WEISS, *Lincoln Laboratory,* MIT.*—Magnetic anisotropy has been observed in evaporated Permalloy films deposited at oblique incidence of the vapor.[1] Electron micrographs reveal chains of crystallites whose long axes are oriented perpendicular to the vapor beam. A difference in the absorption of light polarized parallel and perpendicular to these chains gives rise to optical dichroism. Chain growth cannot be basically a magnetic effect since dichroism has been observed in oblique-incidence films of Ag, Pt, W, and Mg. A "self-shadowing" model is proposed to explain chain growth, i.e., the area behind a crystallite is left vacant because it is in this crystallite's shadow. Experiments involving the stripping of oblique-incidence Permalloy films from their substrates indicate the presence of an anisotropic stress which, when acting through magnetostriction, gives another contribution to the magnetic anisotropy; this contribution explains the observed compositional dependence of the magnetic anisotropy. Surface tension acting on the crystallite chains is postulated as the motivation leading to the anisotropic stress.

* Operated with support from the U. S. Army, Navy, and Air Force.
[1] D. O. Smith, J. Appl. Phys. 30, 264S (1959).

L6. Dielectric Properties of Yttrium Garnet Containing Gallium. ELMER E. ANDERSON, *U. S. Naval Ordnance Laboratory.*—Measurements of dc and ac resistivities and k' have been made on a single crystal of YIG and on polycrystalline samples of YIG with gallium as substituent.[1] The room temperature values of ρ_{dc} are $\sim10^{12}$ and $\sim10^{10}$ ohm-cm, respectively, for the YIG single crystal and YIG polycrystals reported here. Plots of $\ln\rho_{dc}$ vs $1/T$ are linear and have slopes corresponding to activation energies of 0.90 ev for the single crystal and 0.77 ev for the polycrystals. The partial replacement of iron by gallium results in significant decreases in ρ_{dc} and reduces the activation energy of the current carriers to 0.65 ev for a wide range of gallium substitutions. For all samples ρ_{ac} falls off rapidly with frequency to values of 10^3–10^5 ohm-cm at $\sim$10 Mc/sec.

[1] E. E. Anderson, J. Appl. Phys. 30, 299S (1959).

L7. Optical Properties of Gallium-Substituted Gadolinium Iron Garnets. J. E. JACOBS, T. H. RAUTENBERG, AND F. E. WILLIAMS, *General Electric Research Laboratory.*—The transparency to visible light and the Faraday rotation of the ferrimagnetic garnets[1] and the magnetic properties of ferrimagnetic garnets in which part of the iron has been replaced by nonmagnetic ions[2] have been reported. We have investigated the optical absorption and the Faraday rotation of gallium-substituted gadolinium iron garnets $3Gd_2O_3\cdot xGa_2O_3\cdot(5-x)Fe_2O_3$. Both the absorption and the rotation decrease, as expected, with increasing substitution of gallium for the iron. Throughout the wavelength range of 5000 to 10 000 A the absorption coefficients decrease exponentially with gallium substitution and are reduced by a factor of ten at $x=3$. There is also a small shift of the 6000 and the 9000 A absorption bands to longer wavelengths. For gallium substitution with $x>1$, Faraday rotation has been observed only below room temperature. The applied magnetic field required to orient the magnetic domains increases with gallium substitution. The interpretation of these data, particularly as regards the contributions to absorption and rotation of the tetrahedral and octahedral iron ions, and the evaluation of these materials for light valves based on the Faraday rotation, will be discussed.

[1] J. F. Dillon, J. Appl. Phys. 29, 539 (1958).
[2] R. Pauthenet, J. Appl. Phys. 29, 253 (1958); 30, 290S (1959).

L8. Ultrasonic Absorption and Rotational Dispersion in YIG-Crystals. H. BÖMMEL AND K. DRANSFELD, *Bell Telephone Laboratories.*—When passing ultrasonic shear waves through a thin disk of yttrium iron garnet, magnetized in the hard direction with a field around ferromagnetic resonance, we had observed recently a strong acoustic absorption. The high field side of this absorption line is smooth and reproducible. At the low field side, however, the line shape is most irregular, varying from sample to sample. This irregularity is probably caused by nonuniform acoustic bonds between driver-quartz, sample, and receiver-quartz, leading to a nonuniform excitation of magnetostatic modes at lower fields than the uniform precession. We also have found a considerable rotation of the plane of polarization for ultrasonic shear waves propagating through the YIG crystal. For example, at 300 Mc/sec and at room temperature the plane of polarization was turned by about 45 deg in a disk only 0.010 in. thick, at magnetic fields close to the main absorption. Further experiments are in progress to investigate the impurity and temperature dependence of this interaction with the spin system.

L9. Model for Polarization Reversal in Rochelle Salt. H. H. WIEDER, *U. S. Naval Ordnance Laboratory, Corona.*—Nucleation and wall motion of ferroelectric domains were studied by means of the electro-optic Kerr effect and the displacement currents observed during polarization reversal. A theoretical model for the reversal mechanism similar to that proposed for colemanite[1] is shown to be applicable to Rochelle salt. Large internal stresses localized at crystal imperfections inhibit growth of a nucleus except along the ferroelectric axis, and the reversal process is then controlled mainly by the nucleation rate of domains.

[1] H. H. Wieder, J. Appl. Phys. 31, 180 (1960).

L10. Ultrasonic Attenuation in Silver as a Function of Magnetic Field.* EUGENIE V. MIELCZAREK, R. MEISTER, P. MEIJER, J. JALICKEE, AND D. SHELLEY, *The Catholic University of America.*—The ultrasonic attenuation in a single crystal of silver has been measured at 4° Kelvin as a function of magnetic field for several frequencies between 96 and 166 Mc. The crystal was cut with faces perpendicular to the $\bar{1}10$, 001, and 110 directions. Longitudinal waves were propagated in the $\bar{1}10$ direction and the magnetic field was kept perpendicular to this direction. Measurements of relative attenuation have been made with the field parallel to the 100, 111 directions and to various directions in between. The attenuation goes through a maximum and a minimum as the field is varied from 0 to 9000 gauss. The absolute and relative positions of the maximum and minimum at any particular frequency vary as one changes the direction of the magnetic field in the crystal. If we assume that a measurement of the relative positions of the maximum and minimum in a particular crystalline direction give a value of the fermi momentum,[1] we calculate the fermi momentum in the 100 direction to be 0.721×10^{-19} g cm.

* Supported by the Office of Naval Research.
[1] A. B. Pippard, Phil. Mag. 2, 1147 (1957); R. W. Morse, H. V. Bohm, and J. D. Gavenda, Phys. Rev. 109, 1394 (1958); T. Kjeldaas and T. Holstein, Phys. Rev. Letters 2, 340 (1959).

L11. New Galvanomagnetic Effects in *n*-type Germanium below 4.2°K. R. W. KEYES AND R. J. SLADEK, *Westinghouse Research Laboratories.*—Two new galvanomagnetic effects have been found in *n*-type germanium below 4.2°K by employing magnetic field strengths up to 28 000 gauss: (1) magnetoresistance having a different crystalline anisotropy than conduction band magnetoresistance, and (2) a large decrease in the Hall coefficient with increasing field strength. The electrical conductivity of our samples at these temperatures is dominated by impurity conduction. We can interpret the order of magnitude and the crystalline anisotropy of the magnetoresistance as a consequence of changes in the impurity wave functions which are produced by the magnetic field. We can interpret the field dependence of the Hall coefficient as a magnetoresistance effect of the conduction band. This effect occurs because the current due to the Lorentz force is carried by conduction band electrons. Consequently, the effect can be used to determine the conduction band mobility at very low temperatures.

L12. Specific Heat of $Fe_{64}Al_{36}$ from 4°K to 20°K.* H. W. BERNARD† AND M. T. PIGOTT, *The Pennsylvania State University.*—The Sato-Arrott model[1] of the magnetic structure of the alloy $Fe_{64}Al_{36}$ calls for certain magnetic contributions to the total specific heat. The first addition predicted as the temperature is increased is a nearly constant amount of about 300 mcal/mole-deg which persists for several degrees. This is then followed by two peaks. We have measured the heat capacity of a sample of $Fe_{64}Al_{36}$ from 4°K to 20°K. The slope of the c vs T curve is positive and greater between 4°K and 8°K than it is between 8°K and 20°K, qualitatively indicating the initial type of anomaly called for by the model. If the lattice and electronic contributions of $Fe_{64}Al_{36}$ are taken to be identical to those of pure iron, the anomalous specific heat is measured to be about 35 mcal/mole-deg.

* This work was supported by the U. S. Naval Bureau of Weapons and was carried out in the Penn State Low Temperature Laboratory.
† Currently a member of the Penn State Low Temperature Laboratory.
[1] H. Sato and A. Arrott, Phys. Rev. 114, 1427 (1959).

L13. On Flux Trapping in a Superconducting Ring. W. H. MEIKLEJOHN, *General Electric Research Laboratory.*—It is well known that a magnetic field may be trapped in a doubly connected body such as a ring or hollow cylinder. It is shown that the flux trapped upon application and removal of a magnetic field is consistent with calculations. A hollow cylinder of proper geometry will trap a flux proportional to (H_a-H_o) where H_o may be made vanishingly small and H_a is the applied field.

THURSDAY MORNING AT 9:30

Moyse Hall

(V. L. STOUT presiding)

Invited Papers of the Division of Electron Physics, I

M1. Potential Distributions and Operating Characteristics of Low-Pressure Thermionic Diodes. P. L. AUER, *General Electric Company.* (30 min.)

M2. Recent Appearance Potential Measurements by an Electrostatic Electron Selector. LARKIN KERWIN, *Université Laval.* (30 min.)

M3. Photoemission from the Alkali Antimonides. W. E. SPICER, *RCA Laboratories.* (40 min.)

M4. Bounds on Low-Energy Scattering Parameters. L. SPRUCH, *New York University.* (40 min.)

THURSDAY AFTERNOON AT 2:00

Moyse Hall

(R. H. GOOD presiding)

Invited Papers of the Division of Electron Physics, II

N1. Lamb Shifts in Two-Electron Systems. G. HERZBERG, *National Research Council, Canada.* (30 min.)

N2. Electron-Diffraction Studies of Gas Adsorption. L. H. GERMER, *Bell Telephone Laboratories.* (30 min.)

N3. Electron-Interference Observations. L. MARTON, *National Bureau of Standards.* (30 min.)

N4. Significance of Potentials in Quantum Mechanics. N. F. RAMSEY, *Harvard University.* (30 min.)

THURSDAY AFTERNOON AT 2:00

Physical Sciences Auditorium

(G. A. WOONTON presiding)

Invited Papers

P1. Cloud Physics. J. S. MARSHALL, *McGill University.* (40 min.)
P2. Physics of Sea Ice. E. R. POUNDER, *McGill University.* (30 min.)

Sea Ice: Optical and X-Ray Spectra

P3. Salt Distribution in Sea Ice.* J. R. ADDISON, *McGill University* (introduced by E. R. Pounder).—Because of the importance of the role played by the inorganic salts in determining the physical properties of sea ice, work has been performed to ascertain the actual distributions of each of the major component ions as a function of depth from the surface. Natural sea water was frozen at known temperatures under controlled laboratory conditions. The resulting ice was milled, cutting along planes parallel to the surface and 1 mm apart, down to a depth of 10 cm below the surface. The resulting melts were then subjected to quantitative chemical analysis procedures. Sodium, potassium, and calcium were determined by oxyacteylene flame spectrophotometry; magnesium, sulfate, and chloride by colorimetric methods, the latter two involving the use of chloranilate salts. An attempt was made to correlate the distributions found with the phase diagrams for sea ice and previous observations of the freezing of aqueous solutions.

* Work supported by Defence Research Board of Canada.

P4. Distribution of Brine Cells in Sea Ice.* M. P. LANGELEBEN, *McGill University* (introduced by E. R. Pounder).—Long vertical cores of sea ice, extracted from the ice sheet on Hudson Bay near Fort Churchill, have been analyzed at several controlled temperatures. The cores were cut into small lengths and the samples prepared so as to exhibit alternately surfaces corresponding to horizontal and vertical sections. Microphotographs, at magnifications of from about 2 to 6 times before enlargement, were then taken of these surfaces. At temperatures not far below the melting point, the brine appears to be concentrated in thin vertical cylinders of circular or elliptical cross section which may be several centimeters long. With decreasing temperature, the cylinders appear to neck at many points until, at −25°C, the brine is, for the most part, confined in roughly spherical pockets. Horizontal surfaces, in the bottom third of the ice sheet, show domains as large as 1.5 cm across within which the brine cells are arranged along more or less parallel lines, each domain corresponding to an individual crystal. At other levels, the cells are more randomly distributed.

* Work supported by Defence Research Board of Canada.

P5. Directly and Indirectly Produced X-Ray Line Radiation. HAROLD P. HANSON AND DAVID J. COWAN, *The University of Texas.*—By operating at a few kilovolts above the critical voltage, it is possible to make a direct comparison of the number of K x-ray quanta emitted with the number of bremsstrahlung quanta having wavelengths shorter than λ_e that are produced. Simple but realistic geometrical considerations lead to the result that, for a copper target operating at 11.8 kv, about 90% of the K radiation is directly produced. Furthermore, under these conditions, the cross section for K ionization is found to be about 4 times as large as is the cross section for bremsstrahlung production. This result is smaller by at least an order of magnitude than the results predicted by the accepted theoretical equations.

P6. Determination of the Radial Distribution of Brightness in a Cylindrical Luminous Medium with Self-Absorption. MARK P. FREEMAN AND S. KATZ, *American Cyanamid Company.*—The two-path method (utilizing a mirror) is shown to provide sufficient information to solve for the true radial brightness distribution of a luminous medium in the presence of self-absorption. In the case where self-absorption is not large, an approximate solution to the problem is shown to be no more difficult than a solution for the "optically thin" approximation. In addition, reference is made to a numerical technique for forcing a smooth solution to Abel's integral equation.

P7. Emission Spectra from Deposits of Discharged N_2+CO at 4°K and 20°K. I. S. L. N. G. KRISHNAMACHARI* AND R. W. NICHOLLS,† *National Bureau of Standards.*—When the products from a microwave discharge through CO and N_2, over a wide range of mixture ratios, are condensed at 4°K and 20°K, a luminescence of moderate intensity is observed, the emission spectrum of which exhibits 6 strong broad (~10 A wide) bands at the following wavelengths: 3012 A, 3240 A, 3505 A, 3807 A, 4170 A, and 4604 A, in addition to the usual OI and NI features. These bands agree well with alternate members of a series of CO_2 (or CO_2^+ according to Mrozowski[1,2]) bands excited by electron impact on CO_2 by Smyth[3] in the gas phase.

* On leave of absence from Atomic Energy Establishment, Bombay, India.
† On leave of absence from The University of Western Ontario, London, Canada.
[1] S. Mrozowski, Phys. Rev. **60**, 730 (1941).
[2] S. Mrozowski, Phys. Rev. **62**, 270 (1942).
[3] H. D. Smyth, Phys. Rev. **38**, 2000 (1931).

P8. Emission Spectra from Deposits of Discharged N_2+CO at 4°K and 20°K. II. R. W. NICHOLLS* AND S. L. N. G. KRISHNAMACHARI,† *National Bureau of Standards.*—When the products of a microwave discharge through CO and N_2 are condensed at 4°K and 20°K for a few minutes, and the CO flow is then stopped, a very intense yellow luminosity is observed whose emission spectrum contains 17 broad (~30 A wide) bands at 3060 A, 3140 A, 3210 A, 3287 A, 3357 A, 3435 A, 3510 A, 3600 A, 3680 A, 3790 A, 3982 A, 4100 A, 4180 A, 4320 A, 4435 A, and 4580 A, in addition to the usual OI and NI features. The bands correlate well with a number of bands of NCO reported by Dixon[1] from the flash-photolysis of isocyanates in the gas phase.

* On leave of absence from The University of Western Ontario, London, Canada.
† On leave of absence from Atomic Energy Establishment, Bombay, India.
[1] R. N. Dixon, Phil. Trans. Roy. Soc. London **A252**, 165 (1960).

P9. Spectra Emitted from Oxygen-Rare Gas Solids during Electron Bombardment. LOUIS J. SCHOEN, *National Bureau of Standards.*—An electron bombardment technique has been employed to excite light emission in rare gas solids containing small amounts of added oxygen. The Herzberg bands of the oxygen molecule and a strong feature believed to represent

the $^1S \rightarrow {}^1D$ transition of the oxygen atom are observed. In a neon matrix the second negative system of O_2^+ has been identified. The effect of variation of the solid environment on the vibrational structure of the Herzberg bands will be discussed.

P10. Experimental Measurement of the Quadratic Doppler Shift. H. I. MANDELBERG AND L. WITTEN, *Rias.*—The special theory of relativity predicts a quadratic Doppler shift, dependent on $(v/c)^2$, to be present even if a radiating system is viewed at right angles in the observer's system. Ives and Stilwell viewed a moving beam of radiating atoms from the incoming direction and the outgoing direction simultaneously with velocities varying to 2×10^8 cm/sec. Averaging the two observations gave a measurement of the quadratic shift which agreed fairly well with theory but which seemed to show a tendency, as they themselves noticed, to disagree at the higher velocities. The Mossbauer effect recently has permitted a direct measurement of the quadratic shift at low velocities without the need to average. The related time dilation effect has been observed (at high relative velocities but with poor percentage accuracy) by measuring the lifetime of μ mesons produced in the laboratory and by cosmic rays. We have performed an experiment similar to that of Ives and Stilwell using a beam of hydrogen atoms and going to velocities as high as 3×10^8 cm/sec. The use of a Fabry-Perot interferometer allows more reliable measurements than those of Ives and Stilwell and there is no systematic tendency for a discrepancy between theory and experiment.

THURSDAY AFTERNOON AT 2:00

Chemistry Amphitheatre

(H. P. KOENIG presiding)

Cosmic Rays and Space Physics

Q1. Evidence for a Sea-Level Cosmic-Ray Increase of Solar Origin on July 17, 1959. J. F. STELJES and H. CARMICHAEL, *Chalk River Laboratories.*—Cosmic-ray neutron monitor data from more than 30 stations of the IGY network and meson telescope data from more than 12 stations, for the month of July, 1959, generously have been made available to us by private communication. The increase noted[1] on July 17 sharply affected all neutron monitors at sea level or on mountains in both the northern and southern hemispheres where the modified magnetic latitude derived from the formulas of Quenby and Webber was greater than 58° corresponding to a magnetic rigidity of 1.2 Bev/c. For all neutron monitors at smaller latitudes the increase was absent. No meson telescope at any latitude showed a detectable increase. Beyond 62° there was no further increase, presumably because of atmospheric absorption. No variation with longitude was observed. The shape of this solar increase differs markedly from that of the five previously recorded large solar increases all of which reached their maximum within a small fraction of an hour of onset. This one took 6 to 7 hr to reach maximum intensity. The increase of the neutron monitor counting rate averaged from 0000 to 1600 hr Universal Time (UT) on July 17 and was about 5% for stations above latitude 62°.

[1] H. Carmichael and J. F. Steljes, Phys. Rev. Letters **3**, 392 (1959).

Q2. Unusually Sudden Changes of Cosmic-Ray Intensity on July 17 and 18, 1959. H. CARMICHAEL AND J. F. STELJES, *Chalk River Laboratories.*—From many of the stations referred to in the preceding abstract we have also received, by private communication, 10- or 15-min totals from midday on July 17, until midday on July 18. The very sudden fluctuations of sea-level neutron intensity recorded at Deep River[1] around and after midnight UT on July 17–18 were looked for in the records of other stations. They took place, at somewhat smaller intensity, at several other stations in Canada and the U.S.A., but a preliminary search of the records from more distant places indicates that the effect must have been of a remarkably local character. These fluctuations were recorded both by meson telescopes and by neutron monitors.

[1] See footnote 1 of abstract Q1.

Q3. Relative Abundances of Cosmic-Ray Nuclei of Charge $Z \geq 3$ at 136 000 ft. B. JUDEK AND I. J. VAN HEERDEN,* *National Research Council.*—A 3-liter stack of Ilford G_5 emulsions has been flown over Texas at a height of 136 000 ft (residual air pressure 2.7 g/cm²). Charges of 612 heavy nuclei of cosmic radiation entering the stack have been determined using methods of both δ-ray counting and gap counting on the tracks. A good resolution up to a charge of about 7 has been obtained. The results show that the component of cosmic radiation with charge $Z \geq 3$ extrapolated to the top of the atmosphere consists of about 20% of light nuclei ($3 \leq Z \leq 5$), 61% medium nuclei ($6 \leq Z \leq 9$), and 19% heavy nuclei ($Z \geq 10$).

* National Research Council Postdoctorate Fellow. Now at National Physical Research Laboratory, Pretoria, South Africa.

Q4. Radiation Measurements to 1500-km Altitude with Atlas Pods. FRANCIS E. HOLLY, *Air Force Special Weapons Center.*—Three instrument packages, each containing eight geiger tubes, were flown into the inner Van Allen Belt. Various absorber thicknesses were used to obtain range spectra for penetrating particles. Less than 1% of the radiation penetrated 150 mg/cm² of aluminum. The electron spectrum is consistent with a degraded neutron-albedo spectrum and has a high energy cutoff at approximately 800 kev. The proton spectrum was taken to be of the form $N = N_1 E^{-n}$ with n's calculated, at various points during each flight, using data from a pair of counters. n is altitude and/or magnetic field dependent. At points of deepest penetration into the radiation, for two flights (980 and 1100 km) $n = -1.42 (+0.07, -0.09)$ and $n = -1.68$ $(+0.41, -0.38)$, respectively. The proton component penetrating 30 mg/cm² Al absorber was less than $3 \pm (3,5)$% of the total radiation. For radiation penetrating 1.7 mg/cm² of mica and 36 mg/cm² of aluminum no protons were observed within accuracies of 5% and 10%, respectively. Absolute flux intensities have been calculated. The angular distribution of the radiation penetrating the latter two absorbers was observed to be of no greater half-width than $14° \pm 3°$.

Q5. Intensity of Neutron Albedo above the Atmosphere.* S. J. BAME, R. W. DAVIS, AND J. P. GLORE, *Los Alamos Scientific Laboratory,* AND F. B. BRUMLEY, *Sandia Corporation.*

—The high-energy protons in the lower radiation belt have been hypothesized by Singer to arise from the decay of the cosmic-ray-produced neutrons escaping upwards from the atmosphere.[1] Theoretical predictions of the escaping neutron flux have been made by Kellogg[2] and Hess.[3] A measurement of the flux at 44.5°N geomagnetic latitude and up to 120-km altitude has been made with moderated $B^{10}F_3$ proportional counters flown on Deacon-Arrow rockets. The data show a peak counting rate at 16.8 km, falling off to 14% at 46 km, and then to 9% at 120 km. The energy spectrum of Hess[3] and the experimentally determined efficiency function of the counters were used to calculate the flux at 120 km. The value obtained is 0.25 neutron per cm²-sec which compares with ~0.1, predicted by Kellogg[2] for this latitude, and with ~0.7 obtained by integrating the energy spectrum of Hess.[3]

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] S. F. Singer, Phys. Rev. Letters 1, 171; *ibid.* 1, 181 (1958).
[2] P. J. Kellogg, Nuovo cimento 11, 48 (1959).
[3] W. N. Hess, Phys. Rev. Letters 3, 11 (1959).

Q6. (Abstract withdrawn.)

Q7. On the Orbital Motion of Earth Satellites. P. O. BELL, *Hughes Aircraft Company* (introduced by S. J. Klapman).—Y. Kozai[1] has calculated the value of the coefficient A_3 of the third harmonic in latitude of the gravitational potential of the earth to be $(2.20\pm0.08)\times10^{-6}$. The presence of this harmonic accounts for the long-period (80 days) variations in the eccentricity of the Vanguard Satellite (1958 β_2). The objective of the present paper is to derive closed-form solutions of the equations of motion of an earth satellite, of high accuracy (including the effects of the third and fourth harmonics) and without restriction on the orbit inclination angle or eccentricity. The solutions are applicable to time-position prediction of the ephemeris of a satellite. Among the results obtained are the mean rates of (1) the variation of inclination angle of the orbital plane, (2) the regression of the nodes, and (3) the rotation of the line of apsides. The theory shows that i undergoes a small long-period oscillation and the argument of perigee ultimately stabilizes at one of the positions $\omega=\pm\pi/2$, if i is sufficiently near to a certain value (slightly less than $\sin^{-1}(2\sqrt{5}/5)$, which depends upon initial eccentricity and energy of the orbit.

[1] Yoshihide Kozai, Smithsonian Institution, Astrophysical Observatory, Special Rept. No. 22.

Invited Paper

Q8. Recent Progress in the Field of Ionographic (Nuclear) Emulsions. P. DEMERS, *Université de Montréal.* (30 min.)

THURSDAY AFTERNOON AT 2:00

McConnell Engineering Building 204

(OTTO LAPORTE presiding)

Fluid Dynamics I: Shock Waves

QA1. On the One-Dimensional Overtaking of a Rarefaction Wave by a Shock Wave.* G. F. BREMNER, J. K. DUKOWICZ, AND I. I. GLASS, *Institute of Aerophysics, University of Toronto.*—The one-dimensional overtaking of a rarefaction wave by a shock wave is considered for a perfect, inviscid gas. Analytical solutions are presented such that, if the initial rarefaction wave and overtaking shock wave strengths are given, then it is possible to predict the strengths of the reflected and transmitted waves after the interaction as well as the properties of the new-formed quasi-steady regions. Depending on the strength of the overtaking shock wave, the transmitted wave can be a shock wave, Mach wave, or rarefaction wave. It is shown that, for physically available gases in the specific heat ratio range, $1\leqslant\gamma\leqslant\frac{5}{3}$, only a reflected compression wave that steepens into a shock wave is possible after the interaction. For a given set of initial wave strengths the strongest reflected shock wave is produced in a gas with a low specific heat ratio, like SF_6, for example. Numerical solutions have been obtained for four gases of interest in experimental work and are presented in graphical form.

* This work was supported by the Defence Research Board of Canada and the Office of Naval Research (U. S. Navy).

QA2. On the One-Dimensional Overtaking of a Shock Wave by a Rarefaction Wave.* I. I. GLASS, L. E. HEUCKROTH, AND S. MOLDER, *Institute of Aerophysics, University of Toronto.*—Solutions in closed form are given for the overtaking of a shock wave by a rarefaction wave. It is shown that four basic wave systems can result after the interaction consisting of a transmitted shock wave and either a reflected shock or rarefaction wave, or a transmitted rarefaction wave and either a reflected shock or rarefaction wave. The reflected shock waves are produced by steepening compression waves. In all cases the transmitted and reflected waves are separated by a region of variable entropy or contact region. Limiting cases exist where either the reflected or transmitted wave or both simultaneously can be Mach waves. It is shown that for a monatomic gas and for a gas with a specific heat ratio

of unity some of the wave systems do not exist. Numerical solutions have been obtained for four gases of interest in experimental research and are presented in graphical form.

* This work was supported by the Defence Research Board of Canada and the Office of Naval Research (U. S. Navy).

QA3. Slip in Shock Tube Flow.* CHE JEN CHEN AND RAYMOND J. EMRICH, *Lehigh University.*—Recently 0.1-μ cigarette smoke particles in the shock tube boundary layer shear flow have been photographed with an oscillatory spark and a microscopic camera. The photographs show series of streaks for each particle. These particles accurately follow the flow, attaining 99% of the flow velocity in less than 2 μsec. The velocity of the particles at 1 to 5 μ from the wall is observed to be much greater than that predicted by Mirels' theory[1] which assumes no slip at the wall. If the slip velocity is evaluated by extrapolating the experimental velocity profile to the wall, the slip at a certain distance (4.5 cm) behind the shock is about 20 times greater than the value calculated by using Maxwell's slip formula $u_w=\zeta(\partial u/\partial y)_w$. The velocity gradient at the wall $(\partial u/\partial y)_w$ is chosen as Mirels' prediction. ζ is Maxwell's computed slip coefficient. Apparently, these are the first direct measurements of gas velocities within a few microns of a boundary. They may not be characteristic of all gas flows at boundaries since the gas has been set in motion by the shock only about 100 μsec before the measurements are made.

* Supported by the Office of Naval Research and National Science Foundation.
[1] Mirels, National Advisory Committee on Aeronautics, TN 3401 (1955).

QA4. Luminosity behind Strong Shock Waves in Argon.* D. R. WHITE AND R. A. ALPHER, *General Electric Research Laboratory.*—Observations of the luminosity near 4120 A behind Mach 10 to 19 shock waves in argon show that the peak luminosity is proportional to the 1.6 power of the equilibrium electron concentration for concentrations between 1.7 and 17×10^{16} cm^{-3}. No plateau of constant luminosity is observed behind the shock wave, and the inferred rate of decrease in the degree of ionization is in reasonable agreement with the analysis of Pomerantz.[1] Peak luminosity is observed to occur at a time later than attainment of peak ionization as observed interferometrically.

* This research was sponsored in part by the U. S. Air Force under contract.
[1] Jacob Pomerantz, "The influence of absorption of radiation in shock tube phenomena," NAVORD Rept. 6136 (1958), U. S. Naval Ordnance Laboratory, White Oak, Maryland.

QA5. Modified Rayleigh-Philpot Interferometer for Shock-Wave Structure Studies.* GEORGE H. MARKSTEIN, *Cornell Aeronautical Laboratory, Inc.*—A double-slit interferometer of the type[1,2] currently used for diffusion, electrophoresis, and ultracentrifuge studies has been adapted for shock-tube work. In the conventional version of the instrument[2] the cylinder lens which projects the interference fringes on the image of the test section is oriented with the cylinder axis parallel to the refractive-index gradient. Owing to limitations of maximum slit spacing imposed by available light-source intensity, the light paths through both slits had to traverse the test section. Thus, no fringe shifts would have been observed in the conventional arrangement, since the cylinder lens projects the slits upon each other in the direction normal to its axis. The present modification consists of tilting the cylinder axis relative to the refractive-index gradient, thereby causing interference of light coming from regions of different refractive index at the two slits. Interferograms confirming the applicability of the instrument to shock-wave studies have been obtained. The advantages over the Mach-Zender interferometer are greater simplicity and ease of adjustment, lower cost, and the possibility of combining the interferometer with an inclined-slit Schlieren system.[3]

* Work supported by Office of Naval Research through Project SQUID.
[1] J. St. L. Philpot and G. H. Cook, Research 1, 234 (1948).
[2] H. Svensson, Acta Chem. Scand. 4, 399 (1950).

QA6. Cylindrical Shock Waves in a Sector Shock Tube.* ALAN L. COLE, *University of Michigan.*—By using a sector shock tube of 4-in. width, 10-ft length, and 30° flare, cylindrical shock waves with pressure ratios from 1.1 to 33.3 have been produced. Observations have been made with shadowgraph photography while data relating radial distance to time have been secured by means of nine Schlieren light screens and a raster chronograph. A Kistler pressure gage was used to obtain pressure as a function of time. Observations have been made on the following gases: $N_2\rightarrow N_2$, $A\rightarrow A$, $H_2\rightarrow H_2$, $H_2\rightarrow N_2$, $H_2\rightarrow A$, and $H_2\rightarrow SF_6$. The radial distance can be represented as a function of time by an empirical equation of the form $r=b(t-to)^n$. Whereas by dimensional arguments (P. B. Burt[1]) the exponent n should have the value of $\frac{1}{2}$ for an infinitely strong shock produced by a line source, our data give values of n varying between 0.92 and 0.61 depending on the original pressure ratio and the choice of gases. The empirical $r(t)$ curves are differentiated to obtain, through the application locally of the Rankine-Hugoniot equation, the pressure ratio of the shock as a function of r. These values are compared with the values obtained with the Kistler gage and give satisfactory agreement.

* Work supported by the Office of Naval Research.
[1] P. B. Burt, MS Thesis, University of Tennessee, Knoxville, Tennessee. See also E. G. Harris, Naval Research Laboratory Rept. 4858 (1956).

QA7. Studies of the Luminous Gas behind Reflected Shock Waves.* T. D. WILKERSON, *University of Michigan.*—Measurements of pressure and temperature in a shock tube are described. The results bear directly on the calibration of the hot gas behind the reflected shock as a spectroscopic source. On the basis of a few spot-check experiments (covering the ranges of 0.5 to 10 atm in total pressure P and 4000 to 10 000°K in kinetic temperature T), the conditions of the gas near the end wall of the shock tube appear to be very close to those predicted from the primary shock speed by the usual theory. This test of the theory was required in view of the evident nonuniformities of the flow fields arising from boundary layers on the walls. The primary shock waves (Mach 6 to 7) were generated by the expansion of high-pressure hydrogen into neon at initial pressures of 7 to 30 mm Hg. P was measured with a SLM-Kistler PZ 6-S quartz transducer, and T was computed from velocity measurements on the reflected shock and on the fluid to both sides of it. These values of P and T were compared with the values independently calculated from the primary shock speed. All velocities were measured by x-t photography of the luminosity induced by additives. A few microns of CH_4 sufficed to make the shock fronts visible by Swan band emission of C_2, and $CsNO_3$ dust was used to create luminous spots moving with the flow speed.

* Research supported by the Office of Scientific Research, Air Research and Development Command.

QA8. Conical Shock Tube Performance Studies.* V. JOSEPHSON AND R. HALES, *Space Technology Laboratories, Inc.*—The performance of an electromagnetically driven shock generator using a conical discharge tube[1] has been investigated for a variety of voltages and condensor capacitors using air and deuterium at 25- to 1000-μ pressures. Smear photographs and image converter sequential snapshots indicate shock propagation starting at the apex of the cone at a velocity allowing shock arrival at the exit coincident with maximum current "pinching" in the discharge tube. Image converter snapshots also indicate the existence of "sausage" instabilities

in the discharge tube which correlate in time with the "bouncing" on the voltage waveform and also with the origin of the high-velocity nonluminous signals reported earlier.[2] Proper choice of assembly components permits generation of strong single shocks of $M_s \sim 150$ in 100 μ of deuterium.

* Research supported by the U. S. Air Force, Ballistic Missile Division.
[1] V. Josephson, J. Appl. Phys. **29**, 30 (1958).
[2] R. W. Hales and V. Josephson, Bull. Am. Phys. Soc. Ser. II, **5**, 42 (1960).

QA9. Nature of the Fast Front in an Electromagnetically Driven Shock.* R. W. Hales and V. Josephson, *Space Technology Laboratories, Inc.*—Fast fronts have been reported[1] ahead of the shock front produced in a conical shock generator.[2] The velocities observed for these fast fronts are of the order of 10^8 cm/sec. When originally reported, the fast front was characterized by a negative pulse on electrostatic probes. Further studies support the hypothesis that the fast front is caused by deuterons accelerated by the sausage instabilities in the shock generator. These instabilities have been observed in image converter camera pictures. Streak camera pictures have corroborated the results of the probe data on velocities and attenuation, shock generator. Data taken from the probes with the beam passing through a transverse magnetic field are compatible with the axial portion of the beam column being predominantly positive and the outer annuli negative. This would explain the earlier results. The range of the deuterons also can be seen from the probe signals at a pressure of 2500 μ.

* Research supported by the U. S. Air Force, Ballistic Missile Division.
[1] R. W. Hales and V. Josephson, Bull. Am. Phys. Soc. Ser. II, **5**, 42 (1960).
[2] V. Josephson, J. Appl. Phys. **29**, 30 (1958).

QA10. Structure of Magnetohydrodynamic Detonation Waves. C. C. Chang and Y. C. Whang, *University of Minnesota*.—The theoretical structure of detonation waves in the presence of a transverse magnetic field is investigated. We consider the idealized problem of a stationary, infinite plane detonation wave where the flow direction is normal to the wave front and the magnetic field is in the direction parallel to the wave front. We also consider that the chemical reaction process is unimolecular and irreversible, i.e., $A \rightarrow B$. With the consideration of transport properties, such as diffusion, thermal conductivity, and viscosity, the fundamental equations describing the detailed interior structure of the wave front are derived and their solutions discussed. Some numerical solutions for various intensities of magnetic field are carried out by point-to-point integration. The thickness of the detonation wave is obtained. The results also indicate a strong coupling between the reaction zone and the shock zone.

QA11. Frequency Modulation Circuit Measuring Gas Conductivity and Boundary Layer Thickness in a Shock Tube. P. Savic and G. T. Boult, *National Research Council of Canada* (introduced by G. N. Patterson).—A circuit has been built which employs a 10-Mc/sec electronic oscillator, the coil of which is wound around the low-pressure section of a shock tube. The image currents in the conducting gas reduced the effective inductance of the circuit, thus changing its natural frequency by a calculable amount. The frequency change is converted into an amplitude signal by a conventional tuned amplifier limiter and subsequent Foster-Seeley discriminator circuit. It is immaterial whether the gas sample is in motion or not. Theory indicates that the equivalent inductance change is unaffected by the motion of the gas provided that $V/RW \ll 1$, where V is the gas velocity, W the circular carrier frequency, and R the radius of the shock tube. It is shown that for highly conductive gases the skin effect prevents accurate determination of conductivity; the instrument then becomes a device for measuring the thickness of the insulating boundary layer. Preliminary tests indicate that conductivities of the order of 0.05 mhos/cm can still be measured and that the device responds reliably within about 5 μsec.

Thursday Afternoon at 2:00

McConnell Engineering Building 304

(E. A. Frieman presiding)

Plasma Physics, IV

R1. Motion of Charged Particles in Electromagnetic Waves. Erich S. Weibel, *Space Technology Laboratories*.—The motion of a charged particle in an electromagnetic field of the form

$$\mathbf{E}(\mathbf{x},t) = \mathrm{Re}\, i\omega \mathbf{A}(\mathbf{x}) \exp(-i\omega t) \quad \mathbf{B}(\mathbf{x},t) = \mathrm{Re}\, \nabla \times \mathbf{A}(\mathbf{x}) \exp(-i\omega t)$$

is investigated. The orbit of the particle can be obtained approximately as a rapid oscillation $\mathbf{a}(t)$ about a guiding center $\mathbf{r}(t)$ which satisfies the equation

$$\partial^2 \mathbf{r}/\partial t^2 = -\mathrm{grad}\,(e^2 \mathbf{A}(\mathbf{r}) \mathbf{A}^*(\mathbf{r})/4m),$$

while

$$\mathbf{a}(t) = \mathrm{Re}\, i[e\mathbf{A}(\mathbf{r})/m\omega] \exp(-i\omega t).$$

The error in this approximation consists of two parts, $\mathbf{b}_1$ and $\mathbf{b}_2$, of which the first is small of the order $(1/\omega)(eA/m)^2$, independent of time, while the second is of the order $(1/\omega)(eA/m)^2$ but may increase with time at most linearly.

R2. Velocity Moments of the Boltzmann Equation for a System of Charged Particles.* Paul J. Persiani, *Argonne National Laboratory*.—The higher moments of the Boltzmann collision integral are derived for the case of Coulomb interactions. The divergent integrals resulting from small-angle deflections are eliminated by modifying the Coulomb potential or by introducing a cutoff parameter, usually taken as the Debye radius.[1] The form of the collision integral for the ith type particle interacting with a kth type particle is taken as[2]

$$\int_v \chi(v) \frac{\partial f_i(v)}{\partial t}\Big)_{\mathrm{coll}} dv = \sum_k \int_v \int_u \int_\Omega [\chi(v') - \chi(v)] f_k(u) f_i(v) W \sigma \times (W, \Omega \cdot \Omega') d\Omega du dv.$$

The integration of the quantities $\chi(v) = v^n$ over u and Ω gives rise to terms up to the nth-order gradients of scalar functions. Each higher moment introduces a term which is the nth-order gradient of a new scalar function. These scalar functions are defined for the case in which the ratio of the Debye radius to the classical distance of closest approach is very large. The functions for the first and second moment are those derived by Rosenbluth *et al.*[1]

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] M. N. Rosenbluth, W. M. MacDonald, and D. L. Judd, Phys. Rev. **107**, 1 (1957).
[2] W. P. Allis, *Handbuch Der Physik* (1956), Vol. XXI, p. 420.

R3. On the Correspondence between the Solutions of the Collisionless Boltzmann Equation and the Derived Moment Equations.* CARL R. OBERMAN, *Princeton University.*—Many of the results sought in plasma physics depend only on gross properties of the distribution function. For this reason one tries to use a (truncated) set of moment equations to describe the plasma. One then faces the problem of how to perform the truncation with least violence to the physics. Among the truncation schemes used in the past have been (a) the neglect of pressure altogether; (b) the neglect of the equation determining the pressure, which involves heat flow, and the assumption of some sort of equation of state (which?); (c) the neglect of the heat flow term which appears in the equation determining the time rate of change of the pressure. It is the purpose of the present paper to show how to use a finite set of moment equations to describe the plasma when the width (thermal spread) of the distribution function is in some sense small. This description will yield results—for instance, dispersion relations in the linearized theory—to any desired power in the thermal spread, which are in accord with the asymptotic results of the Landau approach to the collisionless Boltzmann equation. The worth of any of the above assumptions is assayed.

* This work was supported under contract with the U. S. Atomic Energy Commission.

R4. Fluctuations of a Plasma.* NORMAN ROSTOKER, *General Atomic.*—We consider a fully ionized plasma. At any time t the state of the system is represented by a point X in the phase space of all the particles. $D_s(X,t;X',t';\cdots X^{(s)},t^{(s)})dXdX'\cdots dX^{(s)}$ means the joint probability that at time t the system will be in (X,dX), at time t' in (X',dX'), etc. A systematic procedure has been developed for calculating any desired moment of D_s as an expansion in the discreteness parameters e, m, and $1/n$. Spectral densities and autocorrelation functions thus can be obtained without any "Stosszahlansatz" or Markoffian assumption. An exhaustive treatment of a plasma in thermal equilibrium has been carried out. A large class of nonequilibrium states may exist in a hot plasma for sufficient time to be considered stationary. Fluctuations have been calculated for the class of spatially homogeneous stable states of an infinite plasma. It is of some interest that thermal equilibrium relationships such as Kirchhoff's radiation law and the fluctuation-dissipation theorem survive. An an application, we have calculated the degree of excitation of the collective modes. For distribution functions which approach instability as some parameter is varied, the energy for some modes becomes very large and ultimately infinite as instability is approached.

* Research on controlled thermonuclear reactions is a joint program carried out by General Atomic and the Texas Atomic Energy Research Foundation.

R5. Plasma Fokker-Planck Equations. A. SIMON, *Oak Ridge National Laboratory,** AND E. G. HARRIS, *University of Tennessee and Oak Ridge National Laboratory.*—We previously have derived[1] a set of first-order (in an expansion in powers of e and $1/V$) kinetic equations for plasma and radiation. The coupled integral equations for the particle-particle correlation $g(1,2)$ and the particle-oscillator correlation $g(1,\lambda)$ now have been solved for the special case of a uniform infinite plasma with no electric or magnetic fields in zeroth order. An exact relativistic solution is obtained using the method of Lenard[2] and Balescu.[3] The resultant particle Fokker-Planck coefficients have both transverse and longitudinal contributions. Each of these, in turn, is composed of stochastic and collective contributions. The longitudinal term agrees with previous results[4] for the special case of an M.B. distribution, but no assumption of a test particle need be made. There is no radiation to this order, but the oscillator frequency is shifted in agreement with the expected dispersion relations.

* Operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.
[1] Albert Simon and E. G. Harris, Phys. Fluids **3**, 245 (1960).
[2] A. Lenard, Project Matterhorn Report MATT-25 (November 23, 1959).
[3] R. Balescu, Phys. Fluids **3**, 52 (1960).
[4] N. Rostoker and M. N. Rosenbluth, Phys. Fluids **3**, 1 (1960).

R6. Boltzmann Equation for an Electron Guide Field Accelerator with Imperfections in the External Focusing Magnetic Field.* JOACHIM B. EHRMAN, *U. S. Naval Research Laboratory.*—A previously obtained solution[1] for the quasi-stationary Boltzmann equation for an electron beam in an external magnetic guide field $\mathbf{B}_0(r)$ is examined for the effect of quasi-stationary imperfections $\mathbf{B}_1$ in this field by linearizing the solutions for $\mathbf{B}_0+\mathbf{B}_1$ about those for $\mathbf{B}_0$. $\mathbf{B}_1$ is taken proportional to $\exp(im\theta)\exp(iz/\lambda)$, and the method previously developed[2] for stability analysis of the unperturbed solution under a time-dependent perturbation is here used to obtain four coupled inhomogeneous Fredholm equations of the second kind for the Fourier components $\rho^{(1)}(r)$, $\rho v^{(1)}(r)$ of the quasi-stationary perturbation. These equations are set up for the case in which $\mathbf{B}_1$ is proportioned to r, independent of θ, and in the θ direction. Then, $\rho v_\theta^{(1)}\equiv 0$. The equations for $\rho^{(1)}$, $\rho v_r^{(1)}$, $\rho v_z^{(1)}$ are simplified in the extreme cases

$$\lambda \ll (p_{\text{longit}}/p_{\text{trans}})r_0 \quad \text{and} \quad \lambda \gg (p_{\text{longit}}/p_{\text{trans}})r_0,$$

where r_0 is the unperturbed beam radius. Results for the Fredholm determinant of the system as a function of λ and $\gamma_0(\gamma_0 m_0 c^2 =$ unperturbed electron energy on the beam axis) are presented.

* Naval Research Laboratory Problem No. 72H01-06.
[1] J. B. Ehrman, Phys. Fluids **3**, 121 (1960).
[2] J. B. Ehrman, Phys. Fluids **3**, 303 (1960).

R7. Fokker-Planck Kinetic Model for a Slightly Ionized Medium in a Constant Magnetic Field.* J. KEILSON AND S. SCHNEIDER,† *Sylvania Electronic Systems.*—To study the electrodynamics of a slightly ionized gas (nonzero collision frequency) in an ambient magnetic field, the Fokker-Planck equation coupled to Maxwell's equations is considered. Within the linear approximation (small departure from equilibrium), equivalent nonlocal equations are derived relating the electromagnetic field directly to the perturbing sources. The effect of the medium is contained in the explicitly given dispersive (wave number and frequency dependent) quantities, the susceptibility and conductivity which appear. This is achieved by integrating out the induced charge and current density expressions. The Green's function for the Fokker-Planck equation in the magnetic field is tractable so this can indeed be carried out explicitly. The Maxwellian equilibrium distribution, which is compatible with the model even in the ambient field, is used. The solution of the purely electromagnetic (linear but nonlocal) equations is immediate in transform space. The response to any desired excitation is obtained by taking the inverse transform which for reasonably simple cases is amenable to actual analysis. Some sample calculations are given to illustrate the procedure.

* This work was performed for the Electronics Directorate of the U. S. Air Force Cambridge Research Center.
† Graduate student at Harvard University.

R8. Ionization Growth in a Gas with an Electric Field.* G. W. STUART AND E. GERJUOY, *General Atomic.*†—A model for the growth of ionization in a gas with a uniform electric field is studied by Laplace transform techniques. The total electron-molecule cross section is taken inversely proportional to the velocity; the ionization cross section may have arbitrary

velocity dependence; all secondary electrons are created with zero energy; all collisions scatter electrons isotropically but produce no energy loss. In the spatially homogeneous time-dependent case that primary electrons are furnished at $t=0$ by a uniformly distributed source, an exact solution is found for the time rate of ionization growth and for the asymptotic (time-growing) electron distribution function integrated over velocity orientation. Numerical results, including effective electron temperatures, are presented for several assumed ionization cross sections. Because of the neglect of energy loss, applicability of the model is limited to the high E/p (electric field/gas pressure) region. Devices which attempt to produce high-energy plasmas for thermonuclear research typically operate in this region.

* Research on controlled thermonuclear reactions is a joint program carried out by General Atomic and the Texas Atomic Energy Research Foundation.
† John Jay Hopkins Laboratory for Pure and Applied Science, General Atomic Division of General Dynamics Corporation, San Diego, California.

R9. Conditions for Maximum Power Transfer to a Plasma. R. GERWIN, J. DRUMMOND, AND B. SPRINGER, *Boeing Scientific Research Laboratories.*—A previous theorem[1] concerning the Vlasov model of an inhomogeneous plasma stated the condition under which power transfer between plasma electrons and a combination of electromagnetic waves and beams is maximized subject to the average electric field energy in the plasma being fixed. This is augmented by the present work which derives the conditions for maximum power transfer between the plasma electrons and the electromagnetic field alone (i.e., without beams). The result is that the electric field must be an eigen function of a certain integral equation on a surface surrounding the plasma.

[1] R. Gerwin, B. Springer, and J. Drummond, Bull. Am. Phys. Soc. Ser. II, 5, 322 (1960).

R10. Model Description of a Partially Ionized Plasma. GILDA HARRIS, JOHN ROBERTS, AND JOHN TRULIO, *Lawrence Radiation Laboratory, Livermore.*—A model for the calculation of the equilibrium properties of a multicomponent plasma has been formulated which includes both bound state and collective Coulomb interactions between nuclei and electrons. The former are treated quantum mechanically, while the latter are described by a semiclassical Debye term. This system is much more complex than a completely ionized plasma. Calculations which start from rigorous quantum or statistical mechanical principles are thus far applicable only to a one-component electron gas in limited density-temperature regions. Therefore, to extend the quantitative description of a plasma to low and intermediate density-temperature regions where bound states are important, it was felt that a more approximate calculation would be most appropriate at this time. Tests of the model are its agreement with experimental results and with the more rigorous calculations. When this model is applied to hydrogen, very good results are obtained in some regions as expected. Also, reasons for its limitations are clearly indicated.

R11. Electric Field Dissociation of Molecular Ions. W. I. LINLOR AND A. W. EHLER, *Hughes Aircraft Company.*—Production of plasma in fusion devices like the DCX of Oak Ridge and the OGRA of the USSR is based on the dissociation of molecular ions while within the confining magnetic field. For a dissociation agent DCX employs an arc; OGRA employs the residual gas. It is possible to employ the *confining magnetic field* itself as the dissociation medium, via the $V\times B$ electric field. Calculations have been made of the necessary electric field strength.[1] The present experiment will describe the apparatus employed in measuring the probability of dissociation per unit time of vibrationally excited molecular ions by intense electric fields. Preliminary results will be presented. Implications for fusion systems will be discussed.

[1] J. R. Hiskes and J. L. Uretsky, University of California Radiation Laboratory, UCRL-8255 (1958); J. R. Hiskes and J. L. Uretsky, Bull. Am. Phys. Soc. Ser. II, 5, 123 (1960).

R12. Oscillating Plane in Magnetohydrodynamics.* J. A. STEKETEE, *University of Toronto* (introduced by G. N. Patterson).—To obtain some information about boundary layers in magnetohydrodynamics the oscillating plane problem of classical viscous flow theory has been studied for an incompressible viscous fluid, which in addition possesses a constant electric conductivity, while a uniform magnetic field in a direction perpendicular to the plane is present. Two penetration depths are present in this problem. For zero magnetic field these are the viscous penetration depth $\delta_V=(\nu/\omega)^{\frac{1}{2}}$ and the electromagnetic skin depth $\delta_B=1/(\sigma\mu\omega)^{\frac{1}{2}}$. It is found that the penetration depths depend on the intensity of the magnetic field; the initially larger penetration depth will increase, while the initially smaller penetration depth will decrease, when the magnetic field increases in intensity. In case $\sigma\mu\nu=1$, and $\delta_V=\delta_B=\delta_0$, one has the explicit expressions for the penetration depths $\delta_{1,2}=\delta_0/(c^5)^{\frac{1}{2}}\pm(\sinh\beta)^{\frac{1}{2}}$, where $\sinh\beta=\sigma B_2^2/4\rho\omega$. The last expression has the form $(\mathrm{Ha})^2/\mathrm{Re}$, where Ha = Hartmann number, Re = Reynolds number. Explicit answers for velocity, induced field, current density, and electric intensity have been worked out for the case $\sigma\mu\nu=1$, with the boundary conditions (a) $E_3=0$ for $x_2=0$, (b) $B_1=0$ for $x_2=0$, (c) $E_3=-UB_2\exp i\omega t$ for $x_2=0$, and the further usual boundary conditions for the velocity at the plate and at infinity and for the magnetic field at infinity. Case (a) corresponds to the magnetic field being "at rest," case (b) to total-vanishing current, and case (c) to the magnetic field moving with the wall.

* This work was supported by the Defence Research Board of Canada.

R13. Plasma Physics and Mathematical Operationalism. JOSEPH G. BARREDO, *C.S.I.C.*—Operationalism deals with observables. The term observable is physically and mathematically ambiguous.[1] Therefore, quantum electrodynamics failed to predict the chronosuperconductivity effect[2] and, consequently, plasma behavior or any behavior for distances $<10^{-13}$ cm. Establishing that every observable is a trion, triondynamics predicted the chronosuperconductivity effect and plasma properties by deducing a time depending law of conductivity applicable to any system of charges (already demonstrated with sampling oscilloscope of rise time $<4.10^{-10}$ sec). Triondynamics also predicts: (1) plasma studies that will permit physics to guide the formation of mathematical concepts as it did before Descartes reversed the process by unifying algebra and geometry through the microphysically meaningless coordinate concept; (2) that this concept must be replaced by the metacoordinate concept,[3] which is a consequence of the charge asymmetry defined by the operation of attraction and repulsion. Contrary to Descartes' opinion, plasma physics indicates that even transcendental knowledge is based on the senses. Thus Russell and Whitehead (following Descartes' criteria) were unable to write Volume IV of *Principia Mathematica* because the observable was undefined.

[1] I. E. Segal, *The Axiomatic Method* (North-Holland Publishing Company Amsterdam, 1959), p. 32.
[2] J. G. Barredo, Phys. Rev. 83, 193 (1951); Bull. Am. Phys. Soc. Ser. II, 5, 172 (1960).

THURSDAY EVENING AT 7:00

Sheraton-Mount Royal Hotel

(V. F. WEISSKOPF presiding)

Banquet of The American Physical Society

After-dinner speaker: J. S. FOSTER

FRIDAY MORNING AT 9:15

McConnell Engineering Building 304

(J. L. TUCK presiding)

Plasma Physics, V

S1. Thermally Ionized Cesium Plasma.* R. V. PYLE, G. PAULIKAS, H. RUGGE, AND J. W. STEARNS, *Lawrence Radiation Laboratory, Berkeley.*—A 200-cm-long, 1-cm-diam column of highly ionized cesium is obtained by directing a beam of neutral cesium atoms from an atomic oven[1] at a hot tungsten filament, which also emits electrons for space-charge neutralization. The plasma is extracted by a negative voltage and guided by a magnetic field. The general approach is similar to that described by Hall and Bekefi.[2] The plasma, which has a density of about $10^{11}/cm^3$, decays slowly with distance from the source and provides an experimental medium that is both well-defined and well-separated from material walls.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Suggested by N. Rynn, Project Matterhorn, Princeton University (private communication).
[2] R. B. Hall and G. Bekefi, Bull. Am. Phys. Soc. Ser. II, 5, 314 (1960).

S2. Generation and Measurement of Highly Ionized Quiescent Plasmas in Steady State. R. C. KNECHTLI AND J. WADA, *Hughes Research Laboratories.*—For research on plasma containment, dense highly ionized quiescent plasmas are useful experimental tools. It has been shown how such plasmas are obtained, combining contact ionization and differential pumping of cesium.[1] The present paper describes another method for producing quiescent, highly ionized cesium plasma columns in steady state, without differential pumping or streaming of neutral cesium. Densities to about 10^{12} ions/cm^3 with 90% ionization have been measured in a quiescent steady state plasma column 10 cm long and 1 cm in diameter contained by a dc magnetic field of a few hundred gauss. (Percentage ionization is defined as the ratio of ion density to neutral plus ion density.) This was close to theoretical expectations. The validity of double probe measurements in dc magnetic field has been verified with this plasma. Measurements on the diffusion of a quiescent plasma in dc magnetic fields are in progress using this cesium plasma. Ultimately this plasma will be used for the investigation of plasma containment by dc magnetic field and rf field combinations.

[1] R. Knechtli and W. Knauer, Bull. Am. Phys. Soc. Ser. II, 3, 81 (1958).

S3. Energy Loss of 300-kev Protons to the Carbon Arc Plasma in DCX. J. A. RAY, C. F. BARNETT, AND J. L. DUNLAP, *Oak Ridge National Laboratory.**—Preliminary measurements have been made for energy loss of 300-kev protons circulating through the carbon arc plasma in DCX. Electron capture collisions between the protons and molecules of residual gas result in energetic neutral atoms escaping from the mirror machine. The atoms are converted to protons by passing through a differentially pumped gas cell. The energy spectrum was obtained with an electrostatic analyzer. With the spectrometer located at the midplane, the peak of the energy distribution was 300 kev, whereas the peak of the distribution was 210 kev with the spectrometer moved 3 cm in the direction of the axial magnetic field. Comparison will be made between the experimental results and the theoretical predictions of Chandrasekhar[1] and Spitzer[2] for the energy loss of an energetic ion in a Maxwellian distribution of cold electrons.

* Operated for the U. S. Atomic Energy Commission by Union Carbide Corporation.
[1] S. Chandrasekhar, Astrophys. J. 93, 285 (1941).
[2] L. Spitzer, Jr., *Physics of Fully Ionized Gases* (Interscience Publishers Inc., New York, 1956), p. 79.

S4. Plasma Heating by Field Mixing. GEORGE SCHMIDT,* *Stevens Institute of Technology.*—By comparing adiabatic and nonadiabatic (irreversible) heating processes it is shown that, while the former uses only a small fraction of the available energy for plasma heating, there is no such limitation with the latter process. One of the powerful irreversible heating processes, field mixing, has been observed experimentally by Kolb[1] *et al.* Although the mechanisms responsible for field mixing are very complex and not well understood, some general statements about its heating effect can be made. Possibilities of using field mixing as an independent plasma heating method are discussed and further experiments suggested.

* Supported by U. S. Air Force Cambridge Research Center contract.
[1] A. C. Kolb, C. B. Dobbie, and H. R. Griem, Phys. Rev. Letters 3, 5 (1959).

S5. Measurements on the Efficiency and Velocity Profile of a Coaxial Crater Pulsed Plasma Motor. W. H. BOSTICK, H. BYFIELD, AND J. NANKIVELL, *Stevens Institute of Technology.*—A coaxial crater pulsed plasma motor shows a fairly constant over-all circuit efficiency of 32% over an operating range of 3 to 30 joules input from the storage capacitor. Plasma energy, momentum, and effective plasma speed have been measured with a calendulum (a combination calorimeter and ballistic pendulum). Velocity profile has been measured with an instrument employing two probes in a magnetic field across which the plasma moves.

S6. Penning Discharge as a High-Energy Plasma Source. R. G. MEYERAND, JR., AND F. SALZ, *United Aircraft Research Laboratories.*—The Penning discharge may be used to produce

a beam of high-energy plasma that is suitable for many experiments in high-temperature plasma physics. Potential gradients eject ions from the discharge, and escaping electrons neutralize the beam. The potential distribution in the source was determined by means of Langmuir probe measurements. The energy of the ions in the plasma beam was determined by a magnetic velocity spectrometer, and good agreement was found between the measured energies and those predicted by the potential distributions. Measurements of the plasma density were made by microwave transmission techniques and correlated with the density measurements obtained from Langmuir probes. The operating characteristics of the discharge were interpreted in terms of the potential distributions and the electron temperatures obtained from the probe curves. The operating characteristics predicted compare favorably with those determined experimentally. Ion currents in the plasma beam in excess of 5 amp have been obtained.

S7. Charged Particle Trajectories through Cusped Magnetic Fields. F. Salz and R. G. Meyerand, Jr., *United Aircraft Research Laboratories.*—A study was performed to determine if a cusped magnetic field could transform a portion of the axial kinetic energy of a beam of charged particles into rotational kinetic energy of the particles about their guiding centers. In this way a beam of charged particles could be used to produce a plasma in which the charged particles possess energy in their center-of-mass coordinate system. Analog computation was used to solve the exact equations of motion of a charged particle in the cusped fields and determine the trajectories. The results showed that as the particle moves through the cusped field a significant fraction of the original axial kinetic energy of the particle is transformed into kinetic energy of rotation around the guiding center of the particle. An idealized model was developed to predict the energy exchange mechanism and was found to agree with the results calculated by the analog computer. The theoretical predictions were correlated with experimental results of plasma beam transmission through cusped magnetic fields.

S8. Possible Applications of Superconducting Solenoids to Plasma Containment and Energy Storage. S. H. Autler, *Lincoln Laboratory.**—Magnetic fields up to 4.3 kgauss, sustained by persistent currents in small superconducting solenoids immersed in liquid helium, have been reported.[1] Recently 4.7 kg at 4.2°K and 6.3 kg at 1.5°K have been attained. Large volume fields at room temperature should be feasible with superconducting coils enclosed in thermally insulating shells. The advantages in power requirements, economy, and field stability over other types of magnets become significant as the size increases. These magnets may be useful for various studies, including low-density plasmas simulating upper-atmosphere conditions. Superconducting compounds such as Nb_3Sn or NbN, known to have high critical fields, might be capable of producing fields of 15 kg or higher. In this range there are many applications to plasma research and possibly thermonuclear machines which use weaker fields but larger volumes than usual. Applications requiring high pulsed currents could use the 1.58×10^8 joules/m³ stored in a solenoid or toroid at 6.3 kg, or the 9×10^8 joules/m³ at 15 kg. The design of superconducting coils and various promising new materials will be discussed.

* Operated with support from the U. S. Army, Navy, and Air Force.
[1] S. H. Autler, Bull. Am. Phys. Soc. Ser. II, 4, 413 (1959); S. H. Autler, Rev. Sci. Instr. 31, 369 (1960).

S9. Energy Balance in a Thermonuclear Reactor.* D. J. Rose, *MIT.*—Energy flow and balance diagrams are presented for a D-T thermonuclear reactor, on the assumption that stability can be achieved. Presence of a neutron moderation blanket appears to preclude fast pulsed operation. For a magnetic mirror system, it is found: (a) the principal energy loss is by particles from the mirrors; (b) for reasonable energy conversion efficiencies, ion temperature $T_i \approx 100$ kev and mirror ratio $R \approx 10$ are required; (c) it is probably necessary to remove the high-energy α particles quickly from the system; this is a difficult task; (d) a maximum magnetic induction ≈ 1.5 weber/m² exists in a long straight section of the mirror; (e) if superconducting solenoids at 1.5 weber/m² can be developed, the efficiency of the system can be improved considerably. Such solenoids do not appear technologically more difficult than supercooled normally conducting ones and offer considerable advantage within their limitation on the induction. Application of superconducting coils to thermonuclear systems other than mirrors is discussed briefly.

* This work was supported in part by the National Science Foundation and in part by the U. S. Army (Signal Corps), the U. S. Air Force (Office of Scientific Research, Air Research and Development Command), and the U. S. Navy (Office of Naval Research).

S10. Neutral Beams as a Probe for Studying Low-Density Plasmas.* K. Rubin, B. Bederson, L. H. Fisher, M. Fuchs, and K. Lulla, *New York University.*—The use of a monoenergetic atomic beam as a probe for studying low-density plasmas is being investigated. The attenuation of a neutral beam passing through a gas is temperature-dependent through the dependence of the collision frequency on the relative beam and mean gas velocities, as well as through the velocity dependence of the scattering cross sections.[1] Plasma temperatures therefore may be inferred from the attenuation measurements, once the velocity dependence of the cross sections are known. Electron and ion temperatures may, in principle, be studied separately because of the difference in recoil scattering angles in the two cases. Preliminary studies are being made by passing alkali beams through a scattering chamber containing a low-density gas (A and He) whose temperature can be varied from 80°K to 800°K. These measurements serve to check kinetic theory predictions and also yield the energy dependence of K-A and K-He scattering cross sections in the energy range 1/12 to 1/30 ev. Work on alkali beams in the energy range 1 to 50 ev is also in progress.

* Supported by the U. S. Atomic Energy Commission.
[1] S. Rosin and I. I. Rabi, Phys. Rev. 48, 373 (1935).

S11. Accuracy of Automatically Plotted Second Derivatives of Langmuir Probe Curves. G. Medicus, *Wright-Patterson Air Force Base.*—The second derivative of the probe current with respect to the probe voltage which is closely related to the energy spectrum of the plasma electrons is plotted automatically by means of the second harmonic method.[1] The second harmonic in the probe current created by a small first harmonic signal superimposed on the dc probe voltage is amplified and rectified by a ring demodulator. The influence of the signal amplitude and of the noise of the plotting system on the accuracy of the results for different characteristic cases of the seond derivative curves is discussed and illustrated by experimental results.

[1] Sloane and McGregor, Phil. Mag. 18, 193 (1939).

S12. Multiple Magnetic Probe Measurements in a Neutron-Producing Magnetically Compressed Deuterium Plasma. H. C. Pollock, L. M. Goldman, and W. F. Westendorp, *General Electric Research Laboratory.*—Six magnetic probes have been spaced equally along the radius of a magnetic compression device previously described.[1] The probes are inserted into a ceramic finger extending to the tube axis and displaced axially 1 in. from the minimum field point between the mirrors. While the presence of the probes reduces the neutron yield, the number remaining, of the order 10^6, is sufficient for accurate measurement of their time distribution relative to the probe signals. The velocity of the current

front is consistent with the velocity of the visible radiation front as measured by a smear camera.

[1] L. M. Goldman, H. C. Pollock, J. Rouvina, and W. F. Westendorp, Bull. Am. Phys. Soc. Ser. II, 5, 309 (1960).

S13. Diffusion and Heat Conduction of a Weakly Ionized Plasma in a Magnetic Field.* D. R. WHITEHOUSE AND G. BEKEFI, *MIT.*—Measurements of electron density and temperature in regions free from ionization and applied electric fields are used in the study of plasma transport properties. In the present experiment, a cylindrical plasma column is maintained at one end by an active discharge, and immersed in an axial dc magnetic field. The electron density is obtained from the loading of a microwave cavity and the electron temperature from the microwave noise emitted by the plasma. From the axial decay of density and temperature, the diffusion coefficient across the magnetic field and the coefficient of thermal conduction along the magnetic field can be inferred. In these calculations the dependence of diffusion and thermal conduction on the temperature can strongly influence the spatial variations. In particular, calculations show that, in the presence of a high magnetic field, the decay in temperature can be sufficiently fast to cause a local increase in electron concentration.

* Supported in part by the U. S. Army (Signal Corps), the U. S. Air Force (Office of Scientific Research, Air Research and Development Command), and the U. S. Navy (Office of Naval Research); and in part by the U. S. Atomic Energy Commission.

S14. Electrical Conductivity in Flame Gases with Large Concentrations of Potassium. G. J. MULLANEY AND P. H. KYDD, *General Electric Research Laboratory,* AND N. R. DIBELIUS, *General Electric General Engineering Laboratory* (introduced by D. R. White).—In the conductivity experiments described in this paper, solutions of K_2CO_3 were used as an additive in propane-oxygen flames at 1-atm pressure. Electrical conductivity was determined with flame temperatures ranging from 1800–2400°K and potassium concentrations from 0.01 to 1.0% by weight of the combustible mixture. Current measurements were made at 1.3 to 50 v dc between an annular graphite ring insert in a zirconia block and a concentric graphite rod. At low potential gradients, the electrical conductivity was limited by the electron density in the gas. At higher voltages for a given gas temperature and additive concentration, the current was determined by thermionic emission from the cathode and the positive ion current in the gas. At constant temperature and voltages below the saturation value, the conductivity increased approximately as the square root of the potassium concentration. A conductivity of 18 mhos/m was obtained with a gas temperature of 2400°K and a potassium concentration of 1% by weight of the combustible mixture. The variation of conductivity with temperature for a fixed amount of additive agreed well with a "free path" kinetic theory method of analysis.

FRIDAY MORNING AT 9:30

Moyse Hall

(R. J. EMRICH presiding)

Invited Papers of the Divisions of Fluid Dynamics and Plasma Physics

SA1. Containment of Positrons in a Magnetic Mirror Geometry. EUGENE J. LAUER, *Lawrence Radiation Laboratory.* (30 min.)

SA2. Experiments on Ion Cyclotron Waves in a Plasma. WILLIAM M. HOOKE, *Princeton University.* (30 min.)

SA3. Experimental and Theoretical Studies of Free-Molecule Fluid Flow. GORDON N. PATTERSON, *University of Toronto.* (30 min.)

SA4. Hypersonic Flows with Dissociated and Ionized Air. HENRY T. NAGAMATSU, *General Electric Research Laboratory.* (30 min.)

FRIDAY MORNING AT 9:30

Chemistry Amphitheatre

(P. DEMERS presiding)

Nuclear Physics, III

T1. Mössbauer Effect in Ferrocyanide. S. L. RUBY, L. M. EPSTEIN, AND K. H. SUN, *Westinghouse Electric Corporation.*—For many purposes it would be desirable to have an iron Mössbauer source or absorber which is monoenergetic. In ferrocyanide, owing to filling and pairing of the iron 3*d* shell by electrons contributed by the cyanogen groups, there is no electronic magnetic moment.[1] This implies that one would expect no internal magnetic field at the position of the iron nucleus. This has been demonstrated using the Mössbauer effect.[2] The hyperfine splitting resulting from a soft iron source and a $Na_4Fe(CN)_6 \cdot 10H_2O$ absorber both at room temperature and at 80°K has been measured. The spectrum is quite different from that obtained with an iron absorber and is consistent with zero magnetic field at the nucleus. An estimate of the Debye temperature for $Na_4Fe(CN)_6 \cdot 10H_2O$, namely, 340°(±40)K, also was obtained from the present measurement. Experiments with a ferrocyanide source also will be discussed.

[1] L. Pauling, *Nature of the Chemical Bond* (Cornell University Press, Ithaca, New York, 1960), 3rd Ed., p. 166.
[2] S. S. Hanna *et al.*, Phys. Rev. Letters 4, 177 (1960).

T2. Nuclear Resonant Absorption in Fe^{57}. M. A. CLARK AND J. M. ROBSON, *Atomic Energy of Canada Limited, Chalk River.*—Measurements have been made of the width and magnitude of the zero-velocity resonance absorption of the 14.4-kev gamma ray in Fe^{57}. The source was 500 μC of Co^{57} plated on $\frac{1}{4}$-mil natural iron foil and diffused into the iron for 24 hr in a hydrogen atmosphere at 1050°C. Relative velocities between the source and natural iron absorbers were imposed by a reversing constant-velocity servo, data being taken only during the constant-velocity portion of the motion in one direction. The detector was a krypton-filled proportional counter having thin beryllium windows. The observed width of the zero-velocity resonance line (0.010 $\pm$0.001 cm/sec) agrees with the natural width predicted from the observed[1] half-life of 1.0×10^{-7} sec. The magnitudes of the resonance peak have been measured for several absorber thicknesses using good geometry and magnetic shielding. The results indicate that f and f', the fraction of emissions and absorptions, respectively, which take place by the nonrecoil process, are at least a factor of two higher than the values reported by De Pasquali *et al.*[2] but are less than predicted by a Debye model using $\theta_D=420°$.

[1] Middelkoop *et al.*, Physica **31**, 897 (1955).
[2] G. DePasquali, H. Frauenfelder, S. Margulies, and R. N. Peacock, Phys. Rev. Letters **4**, 71 (1960).

T3. Muon Scattering from Lead and Carbon at 2 Bev/c.* G. E. MASEK, D. L. HEGGIE, Y. B. KIM, AND R. W. WILLIAMS, *University of Washington.*—A high-energy muon beam was produced at the UCLRL Bevatron from π-meson decays in flight. This beam was used to study high-energy muon scattering, using both counters and emulsions as the detectors. About 2×10^7 muons (with an effective pion contamination of about 10^{-6}) traversed the scattering targets during the counting experiment yielding about 800 scatterings in carbon and 200 in lead over momentum transfers of 100 to 400 Mev/c. Characteristics of the beam will be discussed, and preliminary results of the counting experiment will be presented.

* This work was supported by the Office of Naval Research.

T4. Neutrons from μ^- Capture in Heavy Elements.* C. S. JOHNSON, E. P. HINCKS, AND H. L. ANDERSON, *University of Chicago.*—Neutrons from μ^- capture in Pb, U^{238}, and U^{236} were observed by a time-of-flight technique. The neutrons were detected by proton recoil in a plastic scintillator at a distance 18.5 in. from the target. A traveling wave oscilloscope was photographed to record the time between the incident muon and the arrival of the neutrons. The neutrons obtained from π^- capture were observed with the same arrangement for comparison. Neutrons down to 0.3 Mev were registered with good efficiency. The neutron energy distributions obtained by unfolding the effect of the μ^- lifetimes (80–90 mμ) in these elements will be described. Evidence for prompt neutrons such as might be expected from radiationless μ-mesic atomic transitions in uranium was not found.

* Research supported by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

T5. Gamma-Ray Angular Distributions from $(n,n'\gamma)$ Reactions in Mg^{24}, Mn^{55}, and Fe^{56}.* J. W. BORING AND M. T. MCELLISTREM, *University of Kentucky.*—Angular distributions of prompt γ rays following inelastic neutron scattering were measured from 0 deg to 90 deg with a NaI(Tl) detector mounted in a large collimator of paraffin $+Li_2CO_3$ and lead. Neutrons at an energy of 2.9 Mev and with an energy spread of approximately 170 kev were incident upon solid cylindrical samples. The angular resolution was $\pm$10.5 deg for Mg and Fe and $\pm$17 deg for Mn. The pulsed beam neutron source permitted the discrimination of the prompt gamma rays from neutron induced and other backgrounds by measuring coincidences between the beam pulses and the prompt gamma rays. Beam pulse widths of (11–12)*ns* were used, leading to an over-all instrumental resolution of (12–13)*ns*. Pronounced anisotropies are observed in the gamma-ray distributions.

* This work partially supported by the U. S. Atomic Energy Commission.

T6. Iridium Neutron-Capture Gamma Rays.* P. A. TREADO AND P. R. CHAGNON, *The University of Michigan.*—The gamma-ray spectrum of a sample of natural irridium irradiated by pile neutrons has been measured with a three-crystal scintillation pair spectrometer. The gamma-ray energies found, corresponding to transitions in Ir^{192} and Ir^{194}, were 1.95, 2.48, 2.82, 3.97, 4.19, 4.32, 4.48, 4.79, 4.89, 5.07, 5.19, 5.45, 5.57, 5.68, 5.90, and 6.07 Mev, with approximate relative intensities 20, 20, 15, 4, 3, 3, 4, 2, 2, 2, 1, 2, 1, 2, 1, and 1, respectively. In addition two weak lines believed to be the ground-state transitions were observed at approximately 6.17 and 6.25 Mev, in agreement with the mass-spectrometer measurements of Demirkhanov *et al.*[1] but not with the gamma-ray energy values of Groshev *et al.*[2] and Knoepfel *et al.*[3] The large number of energy values above 4 Mev indicates many transitions below 2 Mev, but an attempt to observe these with a single scintillation counter has not yet been successful.

* Supported by the U. S. Atomic Energy Commission.
[1] R. A. Demirkhanov, T. I. Gutkin, and V. V. Dorokhov, Soviet Phys.-JETP **9**, 1134 (1959).
[2] Groshev, Lutsenko, Demidov, and Pelekov, *Atlas of Gamma-Ray Spectra* (Pergamon Press, New York, 1958).
[3] Knoepfel, Lang, Stoll, and Wolfe, Z. Physik **156**, 293 (1959).

T7. Fast-Neutron Total Cross Sections of Be, C, and O.* D. B. FOSSAN, T. H. MAY, R. L. WALTER, AND W. E. WILSON, *University of Wisconsin.*—The total neutron cross section of C was measured from 3.4 Mev to 13 Mev, the total cross sections of Be and O from 7-Mev to 12.5-Mev neutron energy. Neutrons below 7 Mev were produced by bombarding an about 20-kev thick Zr-tritium target with protons from a tandem electrostatic accelerator. Above 7 Mev (*d-d*) neutrons of about 40-kev energy spread were produced in a gas target. A stilbene scintillator with pulse shape γ-ray discrimination served as a biased proton recoil detector. Sharp peaks were observed in the C cross sections below 8.5 Mev in good agreement with previous measurements. Three broad maxima approximately 0.3 barn high occurred at 9.3, 11.1, and 12.1 Mev with widths of 1.5, 2.0, and 0.5 Mev, respectively. The Be cross section was flat to within 0.3 b. The cross section of O exhibited four peaks, 0.2 to 0.4 Mev wide, at 7.8, 8.3, 8.7, and 9.1 Mev, and two broader peaks at 10.2 and 11.5 Mev. These maxima were from 0.2 to 0.6 b high.

* Work supported by the U. S. Atomic Energy Commission and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.

T8. Differential and Total Cross Sections for Fast Neutrons on Medium Weight Nuclei.* D. W. KENT, SATYA PAL PURI,† WILLIAM P. BUCHER, AND S. C. SNOWDON,‡ *Bartol Research Foundation.*—The total cross sections for fast neutrons incident on twelve elements in the middle atomic weight region have been measured, using *d-d* neutrons with a mean energy of 3.7-Mev and a 400-kev energy spread. Combining the results with our previous measurements at this energy, variation of the total and nonelastic cross sections as a function of atomic weight is obtained in the region $A=32$ to $A=130$ for comparison with optical model predictions. In addition, measurements have been made of the differential cross section for elastic scattering from calcium in the angular range $\theta=10°$ to $\theta=160°$, yielding a value of 3.03 ± 0.21 barns for the integrated elastic scattering cross section. The method in all measurements includes differential pulse-height analysis using an

organic crystal sufficiently small to permit adequate discrimination against γ rays.

* Assisted by the U. S. Atomic Energy Commission.
† Now at the University of Alabama, University, Alabama.
‡ On leave of absence at M.U.R.A., Madison, Wisconsin.

T9. Direct Interaction Inelastic Scattering of 14-Mev Neutrons from Carbon, Oxygen, and Lithium. F. G. J. PEREY,* *Université de Montréal.*—The inelastic differential cross section for the scattering of 14-Mev neutrons from the first levels of C^{12}, O^{16}, and Li^7 have been measured and the results previously reported.[1] In all cases the angular distribution is not symmetrical about 90°. By use of a distorted wave Born approximation due to Glendenning,[2] the differential cross sections were calculated with a square well complex optical potential. It was possible to find a reasonable set of optical potentia! parameters which gave a good agreement with the shape of the experimental cross sections in all cases. The results of the calculations will be presented.

* Holder of a National Research Council of Canada Scholarship.
[1] F. G. J. Perey and P. Lorrain, Bull. Am. Phys. Soc. Ser. II, **5**, 18 (1960).
[2] N. K. Glendenning, Phys. Rev. **114**, 1297 (1959).

T10. Energy Spectra for Several Radioactive Neutron Sources. J. DE PANGHER,* *General Electric Company.*—Ratios of counts for several radioactive neutron sources were measured with the double moderator[1] to investigate possible variations of average neutron energy with source size or to check on previous energy measurements by other methods. It was found that energy spectra for three different sized Ra-α-Be sources were not dependent on source size, but for three different sized PuBe sources the spectra did depend on source size. Measurements made on the National Bureau of Standards source NBS-2 with the double moderator yielded an average energy of 0.20 Mev in disagreement with the value 0.31 Mev obtained from cloud-chamber measurements.[2]

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. De Pangher, Nuclear Instr. and Meth. **5**, 61 (1959).
[2] C. Eggler and D. Hughes, Argonne National Laboratory Rept. ANL-4476 (1950) (unpublished).

T11. Lifetime of Positrons in a Liquid Crystal. E. C. B. PEDERSON, *McGill University.*—Positron annihilation lifetimes have been measured in three phases of the organic substance *p*-azoxyanisole. This substance is an ordinary liquid above 136°C, a solid below 118°C, and a nematic liquid crystal in between. The liquid crystal phase is believed to consist of swarms of about 10^6 molecules all identically oriented, with the separate swarms not correlated in orientation. The results for the liquid crystal phase and the ordinary liquid phases are similar, showing well-defined τ_1 and τ_2 components. The values of τ_2 are 2.1 and 3.6×10^{-9} sec, respectively, with intensity about 20% in each case. The solid phase shows only the τ_1 component. These results show that the regularity of the liquid crystal phase is insufficient to make it behave as the solid does, so far as positron annihilation is concerned.

T12. Scattering of 780-Mev Electrons and Positrons by Electrons.* YANGLAI CHO, E. MALAMUD, AND R. WEILL,† *Cornell University.*—Positrons and electrons are created by passing the bremsstrahlung beam from the Cornell synchrotron through a copper target placed in an analyzing magnet. A second magnet steers the positrons or electrons into a 6-in. diameter propane bubble chamber which is placed in a magnetic field of about 7500 gauss. The mean energy of primary positrons and electrons is reduced by energy loss in the entrance window into the bubble chamber, and its value is calculated from the measured sagitta distributions to be 630 Mev. About 11 000 electron tracks and 19 000 positron tracks have been scanned for scattering events occurring in the chamber. The cross sections are analyzed as a function of the fraction v of the primary energy given to the recoil electron.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† On leave of absence from Laboratoire Recherches Nucléaire, E.P.U L., Lausanne, Switzerland.

FRIDAY MORNING AT 9:30

Physical Sciences Auditorium

(LARKIN KERWIN presiding)

Discharges in Gases

U1. Energetic Deuterium Arc. I. R. J. MACKIN, JR., AND R. A. GIBBONS, *Oak Ridge National Laboratory.*—For some time a program has been under way to develop a gas arc analog of the Luce high vacuum carbon arc. Since the Luce carbon arc has a density of about 10^{14} particles/cc and ion temperatures of the order of tens of electron volts, a similar arc utilizing deuterium instead of carbon might be expected to be fully ionized. Such an arc would be a useful subject for plasma studies in addition to serving as a trapping agent for the DCX injection scheme. The present arc is operated between metal electrodes in a differentially pumped vacuum system and in a magnetic field of 2500 to 5000 gauss. All measurements indicate very stable arc operation using 5 atm cc/sec of deuterium fed into the anode to support a 120-v, 200-amp arc. No problems have arisen with the use of a hollow tungsten cathode. The major anode problems, deterioration and gas-ionizing efficiency, have been solved with fair success by water cooling and pressure baffling, giving about 95% ionizing efficiency. A central vacuum region, partly isolated from both electrodes, is maintained near 10^{-5} mm by ion-pumping action of the arc.

U2. Energetic Deuterium Arc. II. R. A. GIBBONS AND R. J. MACKIN, JR., *Oak Ridge National Laboratory.*—The radiated power from the energetic deuterium arc is about two orders of magnitude less than that from a Luce carbon arc. Nitrogen and argon arcs emit radiation comparable to that of a carbon arc and have been used successfully for wall cleanup. The visible and near ultraviolet spectra from the deuterium arc consist mainly of lines from atomic and molecular deuterium and from ions of carbon and oxygen. The intensity of the carbon lines depends on the cleanness of the system; typically, it corresponds to a partial pressure of 5×10^{-7} mm Hg of carbon monoxide. No serious effort has yet been made

to reduce the level below this value. Spectral line widths, interpreted in terms of Doppler broadening, suggest that the mean energy of the carbon ions is roughly 30 ev and that of the deuterium atoms 4–5 ev. The deuterium atom energies are consistent with those expected from the dissociation of deuterium molecules and molecular ions. Other properties of the arc will be described.

U3. Study of the Low-Voltage Mercury-Alkali Metal Arc. G. H. REILING, *General Electric Research Laboratory.*—Measurements of the arc voltage and electron temperature were made on low-pressure arcs utilizing a mercury cathode containing various concentrations of alkali metals. The arc voltages are substantially lower than the pure mercury arc, and the minimum arc voltage depends on concentration of the alkali metal and ambient temperature of the tube. The cathode fall potential is of the order of 4 v. It is shown that the voltage reduction is mainly in the cathode fall region and that it is lower for rubidium than cesium, potassium, or sodium. There appear to be three processes which together are responsible for the lower energy losses. These are a lower anode work function, a Penning two-stage ionization process of alkali-metal atoms by mercury metastables, and an improved electron emission mechanism. Arc data are presented for mercury cathodes containing Cs, Rb, K, and Na at different concentrations.

U4. Oscillations in Arc Column. C. K. MCLANE, *Speedway Research Laboratory, Linde Company.*—An argon arc is operated between hollow electrodes with axial gas feed at both ends under conditions of pressure and temperature such that the product of electron Larmor frequency and collision time, $\omega\tau$, is of the order 10^3.[1] Electrostatic probes in the vicinity of the arc column near its midpoint reveal oscillations the frequency of which is inversely proportional to the arc length and directly proportional to the magnetic field strength. This suggests that these are standing hydromagnetic waves occurring between arc electrodes. Decay time appears to increase with the square of the arc length, being 3 to 100 μsec for arcs from 3.6 to 17.6 cm long. Mode of oscillation, plasma conductivity, and temperature will be discussed.

[1] This arc is similar to some of those described by J. S. Luce, *Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy* (United Nations, Geneva, 1958), Vol. 31, p. 305.

U5. Stability of Gas and Metal Vapor Arcs. G. A. FARRALL AND J. D. COBINE, *General Electric Research Laboratory.*—The stability of short arcs in gases and in metal vapors is closely related to the phenomena associated with the cathode spot. Use is made of improved techniques, and a considerable range of electrode materials is examined. The distribution of arc life for a given average current is shown to follow the survival law. These data demonstrate that a small percentage of arcs of a given current on very clean metal surfaces may have lifetimes that are extremely short or very long compared with the average life. The relation between the average life of an arc and its average current is shown generally to consist of two sharply defined sections, each of the form $\ln t = A \ln I + B$. The effects of gas and metal vapor on the distribution of lifetimes and the relation between average life and average current are shown for Hg,[1] Cd, Zn, Sb, Cu_2Sb, Bi, Bi-Cu, In, Cu-In, Ag, Sn, Cu_2Sn, Al, Be, Cu, Cu;WTh, Cu;MoC, Mo, WTh, and W. It is shown that high vapor pressure materials tend to produce more stable arcs than those having low vapor pressure. The study includes the effects of several variables such as generator voltage, polarity, gap geometry, and alternating current.

[1] F. Copeland and W. H. Strong, J. Appl. Phys. 16, 302–308 (1945).

U6. Limiting Conditions for Moving Striations in Inert Gases.* A. W. COOPER AND N. L. OLESON, *U. S. Naval Postgraduate School.*—Limiting currents for the presence of moving striations in the positive columns of hot cathode glow discharges in inert gases have been investigated using rotating mirror photography and photoelectric techniques. The critical current decreases monotonically with increasing pressure and increases with increasing tube diameter and distance from the cathode to the point of observation. Critical currents have been measured over a range from 0.15 A to 2 A with a corresponding pressure variation from 0.5 to 15 mm Hg. In small tubes a transition region in the positive column exists where groups of striations are seen. The groups move towards the anode while the striations go towards the cathode. The amplitude is damped in the direction of the cathode. Observation in a tube comprising sections of different diameter show that striation parameters change abruptly in a distance of the order of a wavelength near the junctions. Regular striation patterns in regions of large tube diameter may be separated by sections of smaller diameter showing no coherent oscillation.

* Supported by the Office of Naval Research.

U7. Anode Spot Oscillations in Alkali Vapor Tubes.* HARRY S. ROBERTSON AND M. A. HAKEEM, *University of Miami.*—Anode spot oscillations have been studied in alkali vapor glow discharges, which are free of moving striations. The period of the oscillation is of the order of 100 μsec and varies in a particular tube with current and particle density. Upper and lower current limits for oscillation exist, and these limits depend upon particle density. The amplitude of the tube voltage oscillation is of the order of 1 v and depends upon the series resistance in the circuit. The light intensity from the anode spot is not dependent upon series resistance but usually increases with current. Multiple spots sometimes form, leading to a complex voltage oscillation in which the spots discharge in sequence. A wave of excitation is observable in the plasma, moving toward the cathode at a speed of about 100 m/sec. The phototube shows that this wave becomes rapidly more diffuse as it moves, becoming indistinguishable from the background light emission of the plasma at distances greater than one cm from the anode surface.

* This work was supported by the U. S. Atomic Energy Commission.

U8. Computation of Characteristic Wall Fields and Average Gas Conductivities in an Electrodeless Ring Discharge. HANS U. ECKERT, *Convair Scientific Research Laboratory.*—A previous analysis[1] of a diffusion controlled inductive radio-frequency discharge in an infinite cylindrical tube is extended from vanishing to finite conductivity. Use is made of the existing solution of the wave equation for a cylinder of constant conductivity $\bar{\sigma}$. The expression for the (complex) wave impedance following from this solution provides two relationships between the unknown quantities: conductivity $\bar{\sigma}$, induced electric wall field E_R, phase angle ϕ, and the known quantities: tube radius R, magnetic wall field H_R, and field frequency ω. The required third relationship follows from the solution of the diffusion equation and the boundary condition $\sigma_R = 0$. Numerical results are given for Hg vapor and ways are indicated for obtaining the actual distributions of σ and E across the tube by an iteration procedure.

[1] H. U. Eckert, "Equations of the electrodeless ring discharge and their solution for the breakdown criterion," Proc. IVth Internatl. Conf. on Ionization Phenomena in Gases, Uppsala (1958); also, Convair Scientific Research Laboratory Research Rept. No. 5 (1959).

U9. Momentum Transfer Cross Section for Electrons in Argon.* L. S. FROST AND A. V. PHELPS, *Westinghouse Research Laboratories.*—The momentum transfer cross section for electrons in argon has been deduced from recent measurements of drift velocity.[1] The method involves choosing a trial curve vs energy for the cross section, computing the electron energy distribution functions at several values of E/N the field to pressure ratio, and comparing the resulting computed drift

velocity with the experimental values. The process was repeated eight times to get satisfactory agreement over an extended range of E/N at both 77 and 300°K. The cross section at the Ramsauer minimum is about 1.6×10^{-17} cm² and occurs at ¼-ev energy.

* This work was supported in part by the Advanced Research Projects Agency and the Office of Naval Research.
[1] J. L. Pack and A. V. Phelps (to be published).

U10. Method of Measuring Static Temperature in a Low-Density Gas Flow.* E. P. MUNTZ, *Institute of Aerophysics, University of Toronto* (introduced by G. N. Patterson).—When a collimated beam of electrons of moderate energy (10 to 20 kv) is passed through a low-density jet of nitrogen or air, the emission spectrum obtained is predominantly from the molecular ion N_2^+. At normal temperatures the strongest emission is in the 0—0 band λ3914. Experiments have been conducted to determine the feasibility of measuring the temperature of the gas from the intensity distribution in the rotational fine structure of the 0—0 band. In the experiments a 1.65-mm diameter electron beam, with an energy of 16 600 v and a beam current of 250 μa, was passed through a stream of nitrogen with a static pressure of approximately 150 μ Hg. The temperature of the nitrogen stream was known and could be adjusted from room temperature to 373°K. From the relative intensities of the rotational lines in the 0—0 band ($^2\Sigma-^2\Sigma$ transition) rotational temperatures were obtained. For the experiment the rotational and translational degrees of freedom were in equilibrium, so that a comparison between the spectrographically determined rotational temperatures and the known flow temperatures was possible. For results obtained to date, the spectrographically determined temperatures have been within a maximum deviation of ±2% of the known flow temperatures. This scatter is within the estimated experimental error.

* This work was supported by the Defence Research Board of Canada and the U. S. Air Force Office of Scientific Research.

U11. Energy Transfer from Hot Ions to Cold Electrons.* J. KILLEEN AND W. HECKROTTE, *Lawrence Radiation Laboratory, Livermore.*—A study of the energy transfer from hot ions to cold electrons has been made by means of the numerical solution of the Fokker-Planck equations for the ion and electron distribution functions. An IBM 709 code called DION for solving the equations has been described previously.[1] Two cases of interest are presented. In both cases the electrons are initially at 10 ev. In the first case the deuterons are at 200 kev; in the second case they are at 20 kev. The energy transfer is compared in both cases to that calculated by using the transfer rates given by Spitzer.[2] In both cases the energy transfer rate is less than the value predicted by the quasi-equilibrium theory.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] W. Heckrotte and J. Killeen, Bull. Am. Phys. Soc. Ser. II. 5, 311 (1960).
[2] L. Spitzer, *Physics of Fully Ionized Gases* (1956), p. 79.

U12. Recombination Coefficient for Electrons and Helium Molecular Ions.* E. P. GRAY, *Applied Physics Laboratory, Johns Hopkins University,* AND D. E. KERR, *Johns Hopkins University.*—Electron density measurements made in the afterglow of a He discharge (at 15–20 mm Hg pressure) have been used to calculate the recombination coefficient α for He molecular ions. We have solved a previously described approximation[1] to a diffusion equation containing both recombination loss and an exponentially decaying electron source arising from molecular metastable-metastable collisions. The approximation consists in replacing $\nabla^2 n$ by $-n/\Lambda^2$ (n = electron density, Λ = fundamental diffusion length). The volume average of n, weighted by the square of the cavity electric field, was compared with the measured electron density. Two of the parameters necessary for this comparison, the decay constant and strength of the electron source, were obtained from the pure exponential decay of n at very late times, when all electron loss is presumed due to diffusion of the metastables replenishing the electrons by mutual collision. The only remaining parameter α was then determined by equating measured and calculated values of $\int_0^\infty n dt$, yielding $\alpha=1.3\times10^{-9}$ cm³/sec. The accuracy of this value will be discussed.

* This work supported by the Bureau of Naval Weapons, Department of the Navy.
[1] E. P. Gray and D. E. Kerr, Bull. Am. Phys. Soc. Ser. II, 5, 122 (1960)

FRIDAY MORNING AT 9:15

McConnell Engineering Building 204

(HARVEY BROOKS presiding)

Solid-State Physics, I

V1. Method for Growing Hexagonal HgS Single Crystals. D. L. KINGSTON AND D. C. REYNOLDS, *Aeronautical Research Laboratories.*—Hexagonal mercury sulfide crystals have been grown from the vapor phase by a technique similar to that used for growing cadmium sulfide crystals.[1] In this method a charge of mercury sulfide powder is placed in a Vycor tube which is closed at one end with a flat plate to serve as a substrate. This tube is sealed in a larger tube with an atmosphere of hydrogen sulfide or an inert gas. The whole system is heated so that the charge is at a temperature of approximately 725°C and the substrate at approximately 650°C. Pressures of approximately four atmospheres during growth are used. The growth process involves vaporization of the material from the powder charge and recrystallization on the substrate. The hexagonal structure of the crystals has been verified by x-ray measurements. The crystals are also the characteristic red color of natural cinnabar.

[1] L. C. Greene, D. C. Reynolds, S. J. Czyzak, and W. M. Baker, J. Chem. Phys. **29**, 1375–1350 (1958).

V2. Elastic Waves in Trigonal Crystals.* G. W. FARNELL, *McGill University* (introduced by G. A. Woonton).—In nonisotropic single crystals the normals to the wavefronts of elastic waves are not colinear with the vectors representing either the energy flow or the particle displacement. This paper illustrates some calculations of the propagation characteristics of sound waves in two particular trigonal crystals, quartz and ruby (Al_2O_3). The solution of the equations of motion for the crystal is assumed to be a plane wave with wavefront perpendicular to a given direction.[1] The three velocities obtained from the eigenvalue equation are plotted for many different directions in the crystal. The displacement and energy flow vectors corresponding to each direction are determined for the quasi-longitudinal and the quasi-transverse waves. For both the displacement and the energy flow the results are presented by the points of intersection of the various vectors with a unit sphere.

* Supported by Defence Research Board.
[1] M. J. P. Musgrove, Repts. Prog. in Phys. 22, 74 (1959).

V3. New Method for Measurement of Optical Vibrations in Hydrogenous Substances. B. N. BROCKHOUSE, M. SAKAMOTO, R. N. SINCLAIR, AND A. D. B. WOODS, *Chalk River Laboratories.*—Monoenergetic neutrons of variable energy (E_0) from a crystal spectrometer are scattered by the specimen into a $B^{10}F_3$ counter through a beryllium (or other) filter. The counter is therefore sensitive only to neutrons with wavelength longer than the beryllium cutoff, that is, with energy $E' < 0.005$ ev. The number of counts in the beryllium shielded detector is recorded for a fixed number of counts in a thin counter of known characteristics located in the monoenergetic beam for each value of E_0. A peak in the recorded intensity as a function of E_0 represents a vibration of energy $E_0 - E'$ or about $E_0 - 0.003$ ev. Since the counter is required to detect neutrons of long wavelength only, not much BF_3 is needed and the background is low. The counter can present a large solid angle to the specimen, and so the intensity is high. Difficult corrections for the energy sensitivity of the analyzing spectrometer are eliminated. Measurements at low temperatures are possible. The method shares two disadvantages with the "cold neutron" method: (1) only a limited range of momentum transfers is available, (2) high-energy vibrations are inherently Doppler broadened. Preliminary measurements on LiH show an optical frequency distribution from 0.070 ev to 0.145 ev with a strong maximum at 0.097 ev and a weaker maximum at 0.128 ev.

V4. Phase Transitions in the Ammonium Halides.* RICHARD STEVENSON, *McGill University.*—By use of Bridgman's piston displacement technique, the pressure-temperature phase diagrams of NH_4I, NH_4Br, ND_4Br, NH_4Cl, and NH_4F have been explored. New solid phases have been observed in NH_4I and NH_4F, and new triple points in NH_4I, NH_4Br, and ND_4Br. The phase diagrams of this series of substances exhibit a generalized similarity, and, by using neutron diffraction results on the positions of the ammonium tetrahedra, it is possible to discuss the appearance and nonappearance of the various solid phases in terms of the crystalline electric field. The ordering mechanism which governs the appearance of a number of phases is evidently due to multipole interactions of adjacent ammonium tetrahedra.

* Supported in part by the Office of Naval Research (USA) and the Defence Research Board (Canada).

V5. Scintillation Properties of $CaWO_4$ and $CdWO_4$ Crystals.* G. B. BEARD, W. H. KELLY, AND M. L. MALLORY, *Michigan State University.*—Because of their high densities and high Z's, $CaWO_4$ and $CdWO_4$ crystals have relatively high photoefficiencies with the disadvantage of a long decay time which renders them poor for high counting rate experiments. The effect of temperature on the scintillation efficiencies and decay times of these crystals was studied to see if a more favorable operating temperature could be found. By using a Lucite light piper and a 6292 photomultiplier, the scintillation decay times were found to be 3.3 μsec for the $CaWO_4$ and 2.9 μsec for the $CdWO_4$ for both Po^{210} alphas and Cs^{137} γ rays at room temperature. The value for $CaWO_4$ agrees well with the results of Kallman and Brucker.[1] Both decay times were found to increase by about 20% when the crystals were cooled to liquid air temperature and to decrease by a factor of approximately 3 when warmed to 100°C. The apparent scintillation efficiencies, as determined from the relative pulse heights at the output of a cathode follower, were found to vary inversely with temperature. Preliminary measurements show the variations may not be monotonic. Curves will be presented and the results discussed.

* Supported in part by the U. S. Air Force Office of Scientific Research.
[1] H. Kallman and G. Brucker, Phys. Rev. **108**, 1122 (1957).

V6. Hall Coefficient of Partially Ordered Cu_3Au.* A. R. VON NEIDA AND R. B. GORDON, *Yale University.*—The Hall coefficient R of Cu_3Au has been measured at 300°K and at 78°K as a function of the degree of long range order S and of the antiphase domain size d. With d larger than about 400 A, R changes from negative, through zero, to positive values as S is increased from 0.78 to 0.96. A plot of S vs R shows nearly a straight line relationship, suggesting that the Hall coefficient is a good measure of the degree of long-range order in this alloy. For constant degrees of order within the domains, decreasing the antiphase domain size changes R from positive values characteristic of the fully ordered state to negative values characteristic of the disordered state. These results are explained in terms of the interaction of electrons with domain boundaries. When the domains are very small, R is more negative than in the fully disordered state. Apparently the states in k space separate for electrons moving within domains, changing the relative population of electrons in the conduction band and holes in the valence band. X-ray measurements of d from the broadening of the {100} and {110} lines show, for the most part, good agreement with the previous measurements of Sykes and Jones.

* Supported by the U. S. Atomic Energy Commission.

V7. Magnetoresistance and Hall Coefficient of a Graphite Single Crystal at 4.2°K between Zero and 200 kgauss. W. J. SPRY, *National Carbon Company.*—The magnetoresistance and the Hall coefficient have been measured in the same single crystal of graphite to fields as large as 200 kgauss. The experiment was carried out at 4.2°K in a pulsed magnetic field. The magnetoresistance increases monotonically with the magnetic field, while the Hall coefficient approaches a limiting value. The results will be discussed in terms of an analysis proposed by J. W. McClure.[1]

[1] J. W. McClure, Phys. Rev. **112**, 715 (1958).

V8. Photoconductivity in Cu_2O.* F. L. WEICHMAN, *University of Alberta.*—Photoconductivity and thermoelectric effects were measured on thin plates of multicrystalline Cu_2O mounted between two copper rods in a vacuum container. The apparatus also enabled us to detect the change in thermoelectric effect when light was incident on the Cu_2O plate. The photoconductive response as a function of incident wavelength was measured at a chopping frequency of 40 cycles per sec. The response curves obtained in this fashion at room temperature were found to be independent of the vacuum conditions. However, for a given sample the thermoelectric effects, resistance, and the time constants associated with the photoconductivity were found to be strongly influenced by the atmosphere surrounding the sample. A sample outgassed at 10^{-6} mm Hg at 150°C had a resistance of 2×10^7 Ω and rise times of 1×10^{-3} and 1.4×10^{-3} sec in the visible (600 mμ) and infrared (800 mμ), respectively. The thermoelectric effect was that associated with a hole conductor. When oxygen was let into the vacuum system at room temperature, the sample resistance dropped to 5×10^6 Ω within half an hour. The rise time for the photoconductivity changed to 4×10^{-4} sec. The thermoelectric effect is still that of a hole conductor and is enhanced upon illumination. Subsequent outgassing at 150°C at 10^{-6} mm Hg returned the sample to its original state of higher resistance and longer time constants.

* Supported by the National Research Council of Canada.

V9. P-Type Photoconductivity in Electron Bombarded CdS. B. A. KULP AND R. H. KELLEY, *Aeronautical Research Laboratories.*—A platelet type crystal of pure cadmium sulfide 46 μ thick was irradiated first with 100-kev electrons to reduce the number of sulfur interstitials, then for 450 μa-h/cm^2 with 150-kev electrons to produce an excess of sulfur vacancies. After bombardment, the fluorescence spectrum at liquid nitrogen temperature under uv stimulation showed a broad orange band centering at about 6050 A and a deep red band with

maximum intensity at about 7200 A. The resistivity was 10^{11} ohm-cm. At room termperature three photoconductive peaks were observed at 0.7, 0.9, and 1.4 μ. Point contact rectification was used to determine that the 0.7-μ peak was due to electronic conduction and the 0.9- and 1.4-μ peaks were due to hole conductivity. At liquid nitrogen temperature only the 0.7-μ photopeak was observable. A "quenching" experiment, simultaneous irradiation with band gap and infrared light, at room temperature shows the 0.7-μ photopeak and quenching at 0.9 and 1.4 μ. At liquid nitrogen temperature the 0.7-μ photopeak and 0.9-μ quenching band are present. In a separate experiment the 1.4-μ quenching band was removed from a platelet type crystal by bombarding at 100 kev. This bombardment also removed edge emission from this crystal.

V10. Susceptibility of Photogenerated Carriers in Solids.* C. WEISSFLOCH AND RICHARD STEVENSON, *McGill University*.—A vibrating sample magnetometer of the Foner[1] type was used for a series of room-temperature measurements on the change of magnetic suceptibility when samples of Ge and InSb were irradiated with infrared radiation. The wavelength dependence of apparent susceptibility changes and the dependence on sample carrier concentration were studied. The results are compared with the earlier experiments of Kessler and Moore[2] in order to determine the contribution of excitons to the observed magnetic moment.

* Supported in part by the Office of Naval Research (USA) and the Defence Research Board (Canada).

[1] S. Foner, Rev. Sci. Instr. **30**, 548 (1957).
[2] J. O. Kessler and A. R. Moore, Phys. Rev. Letters **2**, 247 (1959).

V11. Infrared Cyclotron Resonance in Semiconductors.* J. SOSNIAK, *McGill University* (introduced by R. Stevenson).—Cyclotron resonance experiments using monochromatic infrared radiation and pulsed magnetic fields are in progress at the Laboratory. Radiation reflected from the sample surface produces at resonance a signal which is observed by means of a zinc-doped germanium photoconductive detector developed at the Laboratory. The object is to study the band structure of GaSb and InSb by investigating the theoretically predicted shift of the resonance frequency as a function of the magnetic field.

* Supported in part by the Office of Naval Research (USA) and the Defence Research Board (Canada).

V12. Cyclotron Resonance of Negative Mass Carriers under Nonequilibrium Conditions. ROSCOE C. WILLIAMS, *RCA Laboratories*.—The cyclotron resonance spectrum of optically excited carriers in a re-entrant, axially symmetric energy band has been calculated on the basis of classical transport theory. The conditions which the distribution function must satisfy in order that power be emissive at the negative-mass resonance are obtained[1] along with a description of the way in which the power emission varies throughout the negative mass cone. The use of contour integration methods yields an exact evaluation of the power absorption spectrum as a function of the magnetic field and the anisotropy in the distribution function. The poles of the integrand of the power absorption or emission integral give information on the orbits, masses, and frequencies of the carriers undergoing resonance while the residues correspond to the contribution of each carrier to the power absorption or emission. The conditions for emission are demonstrated by calculating the power spectrum for various distribution functions for an energy band model which approximates the heavy hole band of germanium. The results of these calculations will be compared with recent[2] experimental data.

[1] Roscoe C. Williams and Frank Herman, Bull. Am. Phys. Soc. Ser. II, **5**, 61 (1960).
[2] George C. Dousmanis, Robert C. Duncan, John J. Thomas, and Roscoe C. Williams, Phys. Rev. Letters **1**, 404 (1958); R. N. Dexter, D. Hensler, E. Hollar and M. Halloran, Bull. Am. Phys. Soc. Ser. II, **5**, 177 (1960).

V13. Diffusion of Sulfur and Selenium in Gallium Arsenide.* BERNARD GOLDSTEIN, *RCA Laboratories*.—The diffusion of sulfur and selenium into GaAs from a dilute vapor has been studied in the temperature range from 1000°C to 1200°C through the use of radioactive isotopes of these elements and precision sectioning techniques. Penetration profiles were obtained which could be analyzed in terms of the complementary error function. The diffusion coefficients of both sulfur and selenium can be described by the customary equation $D = D_0 \exp(-E/kT)$, where E, the activation energy, is 4.0 ev for both and D_0 is 3×10^7 cm^2/sec and 1×10^7 cm^2/sec for sulfur and selenium, respectively. The fact that this activation energy differs from that found for the diffusion of Cd and Zn in GaAs (2.40 ev)[1] suggests that substitutional acceptor and donor impurities diffuse through their respective sublattices in the III-V compound semiconductors. When dense vapors are used, the formation of secondary compounds or phases was observed between the vapor and the GaAs. GaS was readily observable by electron diffraction methods for the case of sulfur, and an amorphous phase was clearly visible, but not identifiable, for the case of selenium.

* This work was supported by the Electronics Research Directorate of the U. S. Air Force Cambridge Research Center, Air Research and Development Command.
[1] B. Goldstein, Bull. Am. Phys. Soc. Ser. II, **4**, 408 (1959).

V14. Magnetoresistance Effect in Indium Antimonide.* C. H. CHAMPNESS, *McGill University*.—Measurements of weak field magnetoresistance on oriented single crystals of indium antimonide have been carried out at 300°K and 77°K. The results appear to throw doubt on the simple picture for the conduction band of spherical energy surfaces in k space. Preliminary measurements also have been made using pulsed techniques with fields up to 500 kgauss at room temperature in an attempt to observe oscillatory effects.

* Supported in part by the Office of Naval Research (USA) and the Defence Research Board (Canada).

FRIDAY AFTERNOON AT 1:30

Moyse Hall

(WILLIAM SHOCKLEY presiding)

Solid-State Physics, II

W1. Tunneling in InSb. I. Phonon-Assisted Transitions. II. Magnetic Field Effects. A. G. CHYNOWETH, R. A. LOGAN, AND D. E. THOMAS, *Bell Telephone Laboratories*.—Inflections in the differential conductance vs bias curves of narrow InSb p-n junctions at 4°K are well revealed by automatic plotting equipment. The inflection points occur at biases corresponding

to the phonon (or phonon-combination) energies involved. The present precision of the experiments allows these energies to be determined to ±10%. In addition to an inflection at 24 Mev (corresponding to the zero momentum transverse optic, TO, phonon previously reported by Hall[1]), inflections occur at 46, 66, and 84 Mev. These are tentatively interpreted as corresponding to the simultaneous emission of 2, 3, and 4 TO phonons, respectively. Other inflections occur at 5, 11, 36, and 58 Mev, but their exact origins are not understood at present. Magnetic fields cause a reduction in the tunnel current but, as the phonon inflection points continue to occur at the same biases, the reduction in current cannot be caused by series magnetoresistance effects. The way in which the tunnel current depends on H can be accounted for by the increase in the energy gap and the increase in the reduced effective mass with H.

[1] R. N. Hall, Bull. Am. Phys. Soc. Ser. II, 5, 38 (1960).

W2. Effect of Radiation Damage on Excess Current in Esaki Diodes. R. A. Logan and A. G. Chynoweth, *Bell Telephone Laboratories.*—The excess current I_x has been studied in Esaki diodes made by alloying Al+1% B wires on N-type silicon. At forward bias V_x, I_x is given by[1]

$$I_x = A(D_x + \rho_x \varphi t)\exp\left[-\frac{\alpha\omega_1}{2}(\epsilon - eV_x)\right],$$

where D_x is the initial density of states in the forbidden gap and $\rho_x \varphi t$ is that added by bombardment for time t with flux φ of 800-kev electrons at efficiency ρ_x. ϵ is the energy gap, ω_1 is the junction width constant, and A and α are constants. It is confirmed that, at fixed V_x, I_x is linear in φt. It is observed that the logarithm of the slope of this curve varies very nearly linearly with V_x and has the same slope, $\alpha\omega_1/2$, as that of $\log I_x$ vs V_x or $\log I_x$ vs $\epsilon(T)$ within experimental error. This implies that ρ_x is not a strong function of position in the forbidden gap. It is found that 1.3×10^{16} incident electrons increases I_x by 1 amp at $V_x = 0.3$ v independent of the current density. These results are consistent with the mechanism for I_x in which tunneling is via intermediate energy levels in the forbidden gap.

[1] R. A. Logan and A. G. Chynoweth, Bull. Am. Phys. Soc. Ser. II, 5, 160 (1960).

W3. Lattice Vacancies in Neutron Irradiated Germanium. M. C. Wittels, *Oak Ridge National Laboratory.**—Single crystals of high purity p-type Ge having resistivities of 40 ohm-cm were exposed to fission spectrum neutrons in the Low Intensity Test Reactor, Oak Ridge, at a temperature of approximately 85°C. Before and after several exposures to fast neutron fluxes of up to 4×10^{20} neutrons/cm^2 the crystals were examined by both x-ray diffraction and hydrostatic weighing techniques in an effort to establish the nature of the defects produced by fast neutron bombardment. The results of these measurements are that at these dosages and temperatures sufficient defects are trapped so that density reductions as high as 5×10^{-3} develop. In addition, a pronounced variation in the densities as determined by unit cell measurements and those obtained from hydrostatic weighing reveals that the predominant defects stable at room temperature are vacancies.

* Oak Ridge National Laboratory is operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.

W4. Theory of Microplasmas in Silicon Junctions.* R. J. McIntyre, *RCA Victor Research Laboratories.*—Avalanche breakdown in silicon junctions is known to occur at tiny localized regions in the junction. The initial breakdown occurs at just one spot and is characterized by a series of randomly occurring pulses of about 100 μa. A statistical theory to explain this instability has been derived in which the current is assumed to fluctuate about an average value I_0, at which the multiplication factor M is exactly unity. At any other instantaneous current I, the multiplication factor is $M = 1 + dM/dI(I - I_0)$ where dM/dI is negative and results from the effects of the spreading resistance, distributed space charge in the ionized region, and localized heating. Calculations show that, for a typical diode, $I_0 dM/dI \approx -10^{-3}$ so that large fluctuations can be expected. From the calculated probability distribution for the instantaneous current, both the breakdown and turn-off probabilities of the microplasma have been deduced. The results are found to agree both qualitatively and quantitatively with experiment.

* This research was supported by the Defence Research Board of Canada.

W5. Magnetoplasma Resonance in Germanium. R. E. Michel and B. Rosenblum, *RCA Laboratories.*—Microwave plasma resonance has been observed previously[1] in InSb at a fixed carrier concentration. In the present experiments the carrier concentration could be controlled by adjusting the temperature of an n-germanium sample in the 4 to 15°K region. The observations were made at a frequency of 25 000 Mc/sec and with a modulation of the carrier concentration by chopped light. With the magnetic field in a [100] direction a single electron cyclotron resonance line was observed at 4°K. As the carrier concentration was increased by warming the sample, the line was observed to move to lower magnetic field, through zero field, and back to high field as expected. The heavy hole cyclotron resonance line remained in a fixed position as the electron line shifted toward zero field. The effect of the sample depolarization factor (as determined by sample shape) also has been investigated. The results so far obtained are in qualitative agreement with the theory.[1] With the magnetic field in directions other than the [100], the electron line is not single and the effects of this anisotropy on the plasma effects have been studied.

[1] G. Dresselhaus, A. F. Kip, and C. Kittel, Phys. Rev. 100, 618 (1955).

W6. Dislocation Climb in Plastically Deformed InSb.* J. J. Duga and R. E. Maringer, *Battelle Memorial Institute.*—Metallographic observations on plastically deformed single crystal InSb revealed that dislocation climb occurs only under certain specialized conditions. For example, specimens deformed by uniaxial compression exhibited no tendency toward polygonization either during deformation at 300°C or during subsequent annealing at temperatures around 500°C. On the other hand, some degree of polygonization is observed *during* plastic bending, although subsequent annealing at 500°C results only in motion in the glide plane. From analysis of electrical properties in deformed specimens,[1] the nature of the deformation-induced defects has been established. The relation between these defects and etch-pit patterns is discussed. These data are consistent with the three criteria for polygonization: (1) the dislocations must have the edge-orientation, (2) there must be present a sufficiently high density of vacancies, and (3) the strain field associated with the dislocations must be large enough to promote migration of vacancies toward the dislocation core. It is suggested that the presence of Lomer-Cottrell barriers is not the only factor limiting polygonization when intersecting slip systems are activated.

* This work was supported by the Office of Naval Research.
[1] J. J. Duga, R. K. Willardson, and A. C. Beer, J. Appl. Phys. 30, 1798 (1959); J. J. Duga, Bull. Am. Phys. Soc. Ser. II, 3, 378 (1958).

W7. Dislocation Velocities in Germanium and Silicon. J. R. Patel, A. R. Chaudhuri, and L. G. Rubin, *Raytheon Company.*—The method of Stein and Low[1] has been used to measure average dislocation velocities in initially dislocation-free germanium and silicon under various stress conditions. The effects of stress, temperature, and impurities have been determined. This method also permitted a very sensitive determination of the delay time; its dependence on stress and temperature also have been measured. Dislocation velocities are strikingly different in silicon and germanium from those found in LiF and in Si-Fe, in that the velocities become more or less independent of stress at velocities of 10^{-2} to 10^{-3} cm/sec

in the temperature range 400° to 600°C. Average dislocation velocities also were determined from measured values of dislocation density after deforming to the upper yield point, assuming that all dislocations were mobile. Velocities thus measured were lower than those obtained by stress pulsing. This indicates that all the dislocations are not mobile. In fact, for certain orientations only 5% may be mobile. The temperature and strain rate dependence of the strength of germanium and silicon will be discussed in terms of the numbers and velocities of dislocations.

[1] D. F. Stein and J. R. Low, Jr., J. Appl. Phys. 31, 362 (1960).

W8. Measurement of Transmitted Phonon Drag in Silicon.* KURT HUBNER AND WILLIAM SHOCKLEY, *Shockley Transistor Corporation.*—The transmitted phonon drag effect has been used to observe the direct passage of phonons over distances of up to 200 μ and to measure their mean free path at liquid nitrogen temperature. An electric ac field E_{n1} is applied parallel to the p-n junctions in one n-layer of a diffused npn-structure. A field E_{n2} of opposite polarity in the other n-layer indicates the transmitted phonon drag across the p-layer.[1,2] The measurements are taken at 77°K for various widths W_p of the separating p-layer of 10-ohm-cm resistivity. E_{n2}/E_{n1} decreases exponentially with increasing W_p with a characteristic length $L=90$ μ. For the low hole concentration used in the base layer, phonon-phonon scattering is dominant over phonon-hole scattering, and L is therefore the mean free path of those phonons which interact with the carriers due to scattering by the high-frequency phonons. The experiments and the prospects for further investigations are described.

* Supported by the Office of Naval Research.
[1] W. Shockley, *Structure and Properties of Thin Films* (John Wiley & Sons, Inc., New York, 1959), p. 307.
[2] W. Shockley and K. Hubner, Bull. Am. Phys. Soc. Ser. II, 4, 455 (1959).

W9. Relaxation Process for Li-B Ion Pairing.* E. M. PELL, *General Electric Research Laboratory.*—The kinetics observed when Li^+ and B^- ions in Si are allowed to recombine after high-temperature dissociation are characteristic of the more general problem of diffusion limited precipitation to a Coulomb trap. The recombination kinetics were determined by measuring resitivity vs time after the method of Reiss, Fuller, and Morin.[1] As pairing proceeds, the resistivity decreases because of the disappearance of the charged impurity scattering associated with unpaired ions. Measurements were made between 2°C and 35°C. Similar measurements for Li^+ and Al^- in Si have been made by Maita.[2] The present results indicate that the pairing of Li^+ and B^- is largely a random process, though there is evidence for a slight correlation between particular Li^+ and B^- ions. The data are in accord with a model for diffusion-limited precipitation proposed by Ham.[3] Diffusion constants of Li^+ calculated from the kinetics are in accord with previous ion drift results.[4]

* Supported by U. S. Air Force Cambridge Research Center.
[1] Reiss, Fulier, and Morin, Bell System Tech. J. 35, 535 (1956).
[2] J. P. Maita, J. Phys. Chem. Solids 4, 68 (1958).
[3] F. S. Ham, J. Phys. Chem. Solids 6, 335 (1958).
[4] E. M. Pell, Bull. Am. Phys. Soc. Ser. II, 4, 320 (1959).

W10. Electrical Conductivity in Nonstoichiometric Rutile (TiO_2). LEWIS E. HOLLANDER, JR., AND PATRICIA L. CASTRO, *Lockheed Aircraft Corporation.*—Measurements are reported of ρ_a, resistivity in the "a" crystal direction, and ρ_c, resistivity in the "c" crystal direction, on the same crystal specimen for a number of different nonstoichiometric compositions having ρ_c resistivities from 10^{-1} to 10^9 ohm cm. An anisotropy of conduction, ρ_a/ρ_c, in excess of 1000 to 1 has been observed at room temperature. The ρ_a/ρ_c ratio is very dependent on the oxygen vacancy density, being small, 1.5 to 1 in the $\rho_c=10^{-1}$ ohm-cm region and peaking at $\rho_c=10^9$ ohm cm. At higher resistivities this ratio diminishes until, at $\rho_c=10^7$ ohm cm, the ρ_a/ρ_c is only 10 to 1. The resistivity over the range −65°C to +100°C in both crystal directions is presented. These results indicate impurity band conduction predominates at high oxygen vacancy densities, and conventional band gap effects become significant only in the more stoichiometric material. In addition, the transition from one mechanism to the other occurs at very different oxygen vacancy densities for the two crystal directions resulting in large anisotropies in the intermediate region. This model is also in agreement with previous piezoresistive measurements.[1]

[1] L. E. Hollander, Jr., T. J. Diesel, and G. L. Vick, Phys. Rev. 117, 1469 (1960).

W11. Electrical Properties of Type A Zeolite Powder Compacts. W. PERIA, *Honeywell Research Center.*—Conductivity and charge storage measurements on pressed pellets of Linde Type A zeolite will be reported. Such compacts behave as ionic conductors,[1] and the present results suggest that they are two-phase systems. This supposition is further supported by measurements of the frequency dependence of the complex impedance and by conductivity measurements on single polycrystalline particles and on single crystals.

[1] W. Peria, Bull. Am. Phys. Soc. Ser. II, 3, 230 (1958).

W12. Diatonic Scale and the Composition of Crystalline Matter. N. EFREMOV, *600 West 142 Street, New York, New York.*—The relations between the masses of atoms of the elements that compose rockforming silicates can be described in ratios of small whole numbers. Therefore, theoretically the relations between the masses of metallic and silicon atoms which make up these silicates can be calculated, e.g., the relationship between the masses (sum of atomic weights) of the metal atoms and the masses (sum of atomic weights) of the silicon atoms. These ratios of the components of the rockforming minerals can be expressed by the following series:

$$1/2 \quad 8/15 \quad 3/5 \quad 2/3 \quad 3/4 \quad 4/5 \quad 8/9 \quad 1/1 \quad 9/8 \quad 5/4$$
$$4/3 \quad 3/2 \quad 5/3 \quad 15/8 \quad 2/1, \text{ etc.},$$

where the numerators are the masses of the metal atoms and the denominators are the masses of the silicon atoms. When we compare the empirical data concerning the mass relations (atomic weight relations) between the masses of metal atoms and the masses of silicon atoms in the chemical composition of rockforming silicates, we find a good agreement between the theoretically calculated and the empirically established relations. It becomes clear that the basic part of our scale and the musical scale (known as the major diatonic scale) in which these ratios have to do entirely with the vibration frequencies of the notes are the same.

FRIDAY AFTERNOON AT 1:30

Physical Sciences Auditorium

(F. N. FRENKIEL presiding)

Fluid Dynamics, II

WA1. Quasi-One-Dimensional Magnetogasdynamic Flow. J. C. CROWN, *UAC Research Laboratories.*—The flow of an electrically conducting fluid in the presence of a crossed electromagnetic field is analyzed for the case of a compressible, isotropic fluid in which the induced fields are not neglected. The effect of axial area variation is included for flows for which

conditions across the stream are essentially uniform. A method based on an enthalpy-entropy formulation is developed which can be used to obtain flow properties in given channel configurations. In addition, this method can be used in an inverse manner to obtain exact analytic solutions for the physical constraints required to yield various types of idealized flows. Both adiabatic and diabatic flows are considered. Various different flow types are illustrated both by analysis and by numerical calculations.

WA2. Motion of Thin Airfoils and Slender Bodies in Fluids of Arbitrary Electrical Conductivity. E. C. LARY, *United Aircraft Research Laboratories* (introduced by E. L. Resler).—The steady incompressible flow of a nonviscous conducting fluid about thin airfoils and slender bodies is studied for the case of a uniform applied magnetic field aligned with the undisturbed fluid stream. Solutions are found, subject to the restriction of small perturbations to the applied field. The flow for moderate conductivity is characterized by the appearance of a "wake" containing current and vorticity. The wake is roughly parabolic in shape with the body at the focus and may appear either upstream or downstream of the body depending upon the relative magnitude of the stream speed and the applied field. Three regimes of flow, distinguished on the basis of thickness of the wake, are identified and the properties of each are discussed. The lift on airfoils is calculated, including the possibility of magnets and externally driven currents inside the airfoil, and a magnetohydrodynamic analog to the Kutta condition is discussed. Drag formulas are presented for airfoils and slender bodies, and the distribution of internal currents and magnets for zero drag is shown. Optimum drag airfoils and bodies are discussed briefly.

WA3. Investigation of the Stability of the One-Dimensional Flow of a Viscous, Compressible, Heat Conducting, and Chemically Reacting Gas.* J. MENKES, *California Institute of Technology.*—The purpose of the present investigation is to give a concise yet realistic theory of the one-dimensional flow of a real continuous fluid. The mathematical implications inherent in the equations governing such flows, in particular with regard to their stability, are explored in considerable generality. As a concession to mathematical expediency, it was assumed that the Prandtl number is $\frac{3}{4}$ and that the Lewis number is unity. The ensuing simplicity of the equations of motion is a reasonable price to pay for a certain lack of generality. The momentum and energy equations are substantially simplified by the introduction of the stream function as a stream-wise coordinate. The momentum equation (and for that matter the energy and conservation of species equations) is nonlinear in the space-time plane, by virtue of its convective acceleration term, and becomes *linear* once the transformation to the stream-function-time plane is carried out. Moreover, it assumes the well-known form of the diffusion equation in a homogeneous medium. The pressure gradient appears as a "forcing function" on the right-hand side. The whole classical apparatus of dealing with this type of equation can now be brought to bear on this investigation. It is demonstrated that the flow will be stable within the framework of this (linear) stability analysis.

* This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration.

WA4. Viscosity of a Hard-Sphere Fluid.* S. G. BRUSH, T. E. WAINWRIGHT, AND B. J. ALDER, *Lawrence Radiation Laboratory, Livermore.*—It has been shown by Kirkwood,[1] Green, Mori, and others that the transport coefficients of a classical fluid can be expressed in terms of autocorrelation functions of certain microscopic variables pertaining to a small part of the system. In particular, the viscosity tensor may be related to the stress tensor, which can be calculated if one knows the velocities and the forces and distances between all the molecules in the subsystem over a time period characteristic of the regression of fluctuations in this subsystem (Kirkwood's "plateau time"). It is now possible to make calculations on this basis for a hard-sphere fluid, using the method of exact molecular dynamics employing an electronic computer.[2] In this case the stress tensor changes only at collisions, so the time-integrals reduce to sums over the momentum changes which occur at collisions. The results obtained so far will be discussed.

* Supported by the U. S. Atomic Energy Commission.
[1] J. G. Kirkwood, J. Chem. Phys. 14, 180 (1946) and later papers.
[2] B. J. Alder and T. E. Wainwright, J. Chem. Phys. 31, 459 (1959).

WA5. Radial Distribution Function of a Hard Sphere System. E. HELFAND AND F. H. STILLINGER, *Bell Telephone Laboratories.*—An equation for the radial distribution function, $g^{(2)}(r,\lambda)$, of hard sphere molecules of diameter a surrouuding a single sphere of diameter λa is obtained by use of λ as a coupling parameter. When $\lambda=1$, the ordinary radial distribution function is obtained. The equation involves the triplet correlation function. For $\lambda\leq\frac{1}{2}$ the triplet function is given exactly by a product of two $g^{(2)}$'s, one being a contact radial distribution function for which the Reiss, Frisch, Lebowitz[1] value is used. For $\lambda>\frac{1}{2}$ an approximate triplet function must be employed. The advantages of the present technique for hard spheres over the use of potential depth as a coupling parameter[2] are: (1) approximations need be applied only over a limited range of coupling constants; (2) the final equations have a simpler structure; and (3) certain singular behavior is avoided.

[1] H. Reiss, H. L. Frisch, and J. L. Lebowitz, J. Chem. Phys. 31, 369 (1959).
[2] J. G. Kirkwood, J. Chem. Phys. 3, 300 (1935).

WA6. Viscous Magnetohydrodynamic Boundary Layer. A. SHERMAN, *General Electric Flight Propulsion Laboratory.*—In the study of laminar viscous boundary layers in incompressible electrically conducting fluids and in the presence of applied magnetic fields, it is important to determine first the surface pressure distribution due to the interaction between the field and the inviscid flow. Such interaction is not readily obtained for realistic magnetic field configurations since the inviscid flow, in general, will be rotational; however, some calculations have been made for one case[1] which provides the necessary information. In the present investigation, a flat plate boundary layer is analyzed including this particular nonuniform pressure gradient as well as the associated Lorentz force within the viscous layer. Results showing the variation of wall skin friction with distance along the wall will be presented along with the associated velocity profiles. In addition, the influence of the shear in the inviscid flow on the boundary layer development will be discussed.

[1] A. Sherman, *Proceedings of the Sixth Annual Meeting of the American Astronautical Society* (Plenum Press, Inc., New York, January, 1960).

WA7. Measurement of Pressure and Temperature in a High-Speed Plasma Flow.* R. N. GRENDA, *Institute of Aerophysics, University of Toronto* (introduced by G. N. Patterson).—Impact pressures and static temperatures were measured in a high-velocity argon plasma. Gas temperatures were measured spectroscopically using the rotational structure of the (0, 0) NH molecular band at λ3360. Although this gave an effective rotational temperature, it is believed that under the experimental conditions this is close to the translational temperature of the argon. Nitrogen and water vapor impurities caused emission of band spectra from N_2 and OH in addition to NH. It is hoped to obtain verification of the rotational temperature measured with NH by using some of the other observed band structures. The measured tempera-

tures were between 5000°K and 8000°K. The operating static pressure in the plasma jet was about 1 mm Hg. The combination of low pressure and high temperature gave mean free paths which were almost large enough to produce free molecule flow with respect to the pressure probe. From measurements of impact and static pressure, and the rotational temperature, the flow velocity was calculated.

* This work was supported by the Defence Research Board of Canada

Post-Deadline Papers, If Any

FRIDAY AFTERNOON AT 1:30

Chemistry Amphitheatre

(R. E. BELL presiding)

Nuclear and General Theory

X1. Theory of Reactions Involving Light Nuclei. J. E. YOUNG AND P. R. STEIN, *Los Alamos Scientific Laboratory.*—By proceeding from the theoretical description provided by multiple scattering theory, we are able to obtain a reaction model applicable to nucleon interactions with light nuclei. The essential feature of the method is to develop polarized wave functions. These, in turn, are employed to compute the matrix elements of all two-body interactions between target and external nucleons. The latter are characterized by the Yamaguchi separable nonlocal t matrix. The technique has been applied to reactions for the $A=4$ system, for which some theoretical cross sections are to be presented. In the case of n-d scattering, $A=3$, the technique has to be slightly modified and preliminary computations are being undertaken.

X2. Tables of Rotational Energy Levels of Deformed Even-Even Nuclei. R. B. MOORE AND W. WHITE, *McGill University* (introduced by J. S. Foster).—These tables are related to the axially asymmetric neuclei as actively developed by Davydov and Filippov. The present work was stimulated by the recent realization of high spin states by Coulomb excitation. Calculations of rotational energy levels given by the Hamiltonian

$$H=\frac{\hbar^2}{4B\beta^2}\sum_{i=1}^{3}\frac{I_i^2}{2\sin^2[\gamma-(2\pi/3)i]}$$

have been performed by a digital computer. For convenience in applications, levels as functions of γ are expressed in terms of the first rotational level.

X3. Statistical Weights in the Theory of Multiple Particle Production. J. SHAPIRO, *Fordham University.*—In applying statistical theories to multiple particle production, the problem arises of finding the statistical weight for producing a final state with definite numbers of particles of various types and charges (for example, 1 proton, 5 positive, 4 neutral, and 4 negative pions in a pp collision), assuming conservation of total isotopic spin and charge. The usual method,[1] which involves the successive combination of isotopic spin wave functions using Clebsch Gordon coefficients, becomes extremely complicated if many particles are involved. A simple explicit formula for these weights has been obtained by the use of angular momentum projection operators.

[1] R. H. Milburn, Revs. Modern Phys. **27**, 1 (1955).

X4. Diffraction Inelastic Scattering of Alpha Particles.* E. ROST† AND N. AUSTERN, *University of Pittsburgh.*—The method of distorted wave Born approximation has been used to calculate the angular distribution of alpha particles inelastically scattered from strongly absorbing nuclei. Convenient distorted wave functions, given in spherical harmonic expansion, are those of the sharp-cutoff black sphere model. These are improved by "smoothing" the cutoff over several partial waves. The calculations assume a surface interaction and are specialized thus far to reactions with $L=2$ angular momentum transfer. They are performed on an IBM 650 computer. Our calculations are directly comparable to the adiabatic calculations of collective excitation considered by Blair in Fraunhofer approximations,[1] and good agreement is found at forward angles. Toward larger angles our differential cross section becomes very much smaller than his, the oscillations are damped, and the peaks are displaced toward larger angles. It also is noted that the successive minima are roughly equally spaced in scattering angle, and that the results are not sensitive to the Q of the reaction. It will be shown that these features agree with experiment.

* Work done in the Radiation Laboratory and assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† National Science Foundation Cooperative Graduate Fellow.
[1] J. S. Blair, Phys. Rev. **115**, 928 (1959).

X5. Green's Functions for the Klein-Gordon Equation in n-Dimensions. JOHN J. BOWMAN, *Dartmouth College.*—An explicit form of the Green's function $\Delta_n(S)$ for the Klein-Gordon equation in multidimensional spaces has been obtained. The difference between spaces with an even and an odd number of dimensions is reflected in the nature of the singularities on the light cone. For spaces with an odd number of dimensions the Green's function consists of a linear combination of a finite number of derivatives of the Dirac delta function $\delta(S^2)$, where $S=(x_0^2-x_1^2-\cdots-x_n^2)^{\frac{1}{2}}$ is the space-time distance. The highest order derivative appearing in the linear combination is of order $(n-3)/2$, where $n=3, 5, 7, \ldots$ is the dimensionality of the space. There also appears a finite jump discontinuity involving a Bessel function. The singular part of the Green's function for spaces with an even number of dimensions consists of a polynomial in $1/S$ of degree $n-1$.

X6. Influence of the Pauli Principle on Low-Energy Electron-Hydrogen Scattering. BERNARD A. LIPPMANN AND HARRY M. SCHEY, *Lawrence Radiation Laboratory, Livermore.*—If the electron-hydrogen scattering problem is reduced to an equivalent one-body problem by the use of an optical model potential, the Pauli principle reduces, for the triplet state, to a simple orthogonality condition. We have analyzed the influence of the Pauli principle by calculating the scattering cross sections for the two cases where this condition is and is not satisfied. For a long-range optical potential (shielded coulomb plus polarization potential), where most of the scattering occurs far from the region where the Pauli principle would be expected to operate, the effect of the orthogonality condition is small; however, for a short-range potential (shielded Coulomb potential only), the Pauli principle changes the zero-energy cross section by an order of magnitude.

X7. Monte Carlo Calculations of Electron Backscattering. CRAWFORD MACCALLUM, *Sandia Corporation* (introduced by R. S. Claassen).—Although the cross sections which govern the scattering and energy loss of fast electrons in solids are well known, the mathematical problem of deducing the number and the energy and angular distributions of electrons backscattered out of the solid is unusually difficult. Monte Carlo calculations have been performed for various materials at energies from 10 kev to 500 kev. These agree well with experimental results where they exist and shed new light on (1) the relativistic decrease in backscattering coefficient, (2) the increase in coefficient with angle of incidence, (3) the importance of the single parameter $d\Theta^2/d\ \ln E$ which can be determined from theory (Θ^2 = mean square angular deviation from forward direction, E = energy), (4) the influence of energy loss straggling and the production of delta rays on the energy and angular spectra.

X8. Feynman Diagram Method Used in the Derivation of the Transport Equation. K. NISHIKAWA,* *Université de Montréal* (introduced by R. J. A. Lévesque).—The Feynman diagram method is applied to irreversible processes in a large Fermion system. By using a linked cluster expansion, the von Neumann equation for the density operator is rewritten in a form convenient for studying the long time behavior. The basic assumptions are (1) short-range character of correlations between particles, (2) separability of the spatial inhomogeneity into two differentiable parts (macroscopic and microscopic), and (3) smallness of the spatial inhomogeneity. Then the contribution of each vacuum linked diagram is shown to be proportional to the volume but generally to diverge for high powers of the time. This divergence difficulty is removed partly by considering certain complementary diagrams and partly by renormalizing the propagators. For a homogeneous system, the master equation is derived as before,[1] while for an inhomogeneous system a Uehling-Uhlenbeck type equation is obtained for a "coarse-granied" single-particle phase-space distribution function in the two limiting cases, weak coupling and low-density limits. Comparison with the results of Prigogine and his collaborators will be given.

* On leave from the University of Tokyo, Japan.
[1] K. Nishikawa, J. Phys. Soc. Japan 15, 78 (1960).

X9. Nonlinear Generalization of a Vector Field. H. SCHIFF, *University of Alberta.*—Relativistically invariant nonlinear equations are developed for a six-vector field including self-interaction and mass terms of which the Maxwell field is a special case. Thus the electromagnetic and nonzero mass fields can be considered as arising from the same basic equations. In the static case, discrete spherically symmetric solutions exist representing exponentially localized energy and charge regions which are finite everywhere. The mass spectrum and the strength of the self-interaction will be discussed.

X10. Transformation Behavior and Dimensional Properties of Physical Fields. E. J. POST, *Bell Telephone Laboratories.*—This paper discusses the relation between the physical dimensions of physical quantities and their transformation behavior in space-time. An invariant dimensional characterization in four-space appears possible, but only in connection with an "essential" dimensional distinction between space and time coordinates. The compatibility of general covariance and the dimensional individuality of space and time coordinates requires "action" and "charge" as the two invariant physical units, whereas length and time are exclusively associated with the transformation behavior of the fields. The application of these principles yields a unique classification of physical fields in terms of dimensional properties and transformation behavior.

X11. Structure of Nucleons and Conservation Laws. J. BARNOTHY, *Evanston, Illinois.*—High-energy electron scattering experiments have been interpreted as evidence for the finite size of nucleons. A model is proposed, based on the assumption that elementary particles are closed universes with smaller length and mass units. Embedded in a four-dimensional continuum they become observable when they intersect our space. Nuclear forces reveal themselves as gravitational forces between rest masses, defined by the gravitational and cosmological constant of the smaller worlds. An intersection of our space with a smaller world from the "right" represents a particle, from the "left" an antiparticle. Leptons, baryons, and (K and pi) mesons correspond to different cosmological solutions. All neutral particles are combinations of charged particles. The inability to distinguish between "right" and "left" sides of our space leads to the lepton and baryon conservation laws. Strong interactions are symmetrical in the fourth dimension and manifest parity conservation in the usual three-dimensional description. Weak interactions are asymmetrical in the fourth dimension and will obey parity conservation only if the fourth coordinate, i.e., particle to antiparticle change is also considered. At present, scattering energies, deviations from point scattering laws, are not a consequence of the finite size of the nucleons. The theoretically derived form factors agree well with the experimental results.

X12. Is the Red Shift a Doppler Effect? M. FORRO AND J. BARNOTHY, *University of Illinois.*—Metaphysical creation acts inherent in present-day cosmologies were forced upon us to reconcile the expansion of the universe with the finite density of matter and to escape difficulties connected with static cosmological solutions. It will be shown that the explanation of the red shift as a Doppler effect is not based on adequate experimental evidences and that the equilibrium of a static universe is not necessarily labile. To cope with problems like red shift, cosmological term, Olber's paradox, and entropy death, the assumption is made that the metric of signal carriers changes relative to the metric of elementary particles. In a steady-state universe, this change has to be an exponential function of time, with positive, negative, or imaginary exponent. The case of positive exponent is realized in the electromagnetic radiation, leading to a nonlinear red shift, excess reddening, cosmic radiation, and material for star formation. The case of an imaginary exponent leads to the cosmological term of the gravitational field. A negative exponent would necessitate metaphysical creation acts to maintain conservation of energy, unless, as in case of nuclear interactions, the uncertainty relation can be evoked.

FRIDAY AFTERNOON AT 1:30

McConnell Engineering Building 204

(P. A. REDHEAD presiding)

Molecular and General Physics

Y1. Elastic Scattering of Electrons by Atomic Hydrogen.* H. B. GILBODY, R. F. STEBBINGS, AND WADE L. FITE, *General Atomic.*†—The angular distribution of electrons scattered elastically by hydrogen atoms has been determined for electron energies below 10 ev. The elastically scattered electrons arising from the interaction of crossed electron and modulated hydro-

gen atom beams were examined over an angular range extending from 30° to 120°. The results will be discussed with reference to other recent experimental and theoretical developments.

* This work was carried out under a joint General Atomic-Texas Atomic Energy Research Foundation program on controlled thermonuclear reactions.
† John Jay Hopkins Laboratory for Pure and Applied Science, General Atomic Division of General Dynamics Corporation, San Diego, California.

Y2. Apparatus for Mass Spectrographic Studies of Low-Energy Ion-Molecule Reactions.* E. W. McDaniel and D. W. Martin, *Georgia Institute of Technology.*—Phenomena such as charge transfer and ionic clustering and dissociation play an important role in gaseous electronics. An instrument constructed for the study of such reactions at very low (down to thermal) energies is described. Positive ions are produced in a thermionic source utilizing a thoriated iridium filament which is located inside a 3-ft-long drift tube containing gas at 0.01–1.0 mm Hg. The ions drift down the tube under "low-field" conditions and pass through a small aperture at the end into a field-free, two-stage differential pumping chamber. From the second stage of this chamber the ions enter a 60° magnetic deflection mass spectrometer. The number of ion-molecule collisions in the drift tube may be varied over a wide range by moving the ion source along the tube and by changing the drift tube pressure, and reaction cross sections are estimated from the resulting changes in mass spectra. Data obtained with this apparatus will be presented.

* This research was supported by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command.

Y3. Nitrogen, Oxygen, and Argon Ion-Molecule Collisions. William McGowan and Larkin Kerwin, *Université Laval.*—A mass spectrometer has been used to study some ion-molecule collisions in atmospheric gases. The ion energy used varied from 500 ev to 2 kev. Of particular interest are charge exchange reactions similar to

$$N_2^{++}+N_2 \rightarrow N_2^{+}+N_2^{+}$$

for nitrogen, oxygen, and argon, and dissociation processes like

$$N_2^{+}+N_2 \rightarrow N^{+}+N+N_2$$

for nitrogen and oxygen. Cross sections for these reactions will be proposed and their energetics will be discussed.

Y4. Charge Transfer between Atomic Hydrogen and Ions of Oxygen and Nitrogen.* R. F. Stebbings, Wade L. Fite, and D. G. Hummer,† *General Atomic.*‡—The cross sections for charge transfer in collisions between atomic hydrogen and singly charged atomic ions of oxygen and nitrogen have been measured within the energy range 400–10 000 ev. The experiment employed crossed-beam and modulation techniques. Comparison between the experimental results and recent theoretical work is made.

* This research was supported by the Advanced Research Projects Agency through the Office of Naval Research.
† Present address: Department of Physics, University College, London, England.
‡ John Jay Hopkins Laboratory for Pure and Applied Science, General Atomic Division of General Dynamics Corporation, San Diego, California.

Y5. Dissociation of H_2^+ by Hydrogen. Herman Postma and David P. Hamblen, *Oak Ridge National Laboratory.*—The dissociation cross section of H_2^+ by hydrogen has been measured for energies 200 kev through 600 kev. A H_2^+ beam incident upon a differentially pumped hydrogen gas target was electrostatically analyzed for H_2^+ and its dissociation products H^0 and H^+. Detection was made by a Faraday cup and secondary electron collector. Both the total loss cross section for H_2^+ and the proton production cross section are in close agreement with the results reported by Sweetman[1] for energies 200 kev through 500 kev and with Barnett[2] for energies 500 kev through 600 kev.

[1] D. R. Sweetman, Phys. Rev. Letters 3, 425 (1959).
[2] C. F. Barnett, *Proceedings of the Second United Nations Conference on the Peaceful Uses of Atomic Energy* (United Nations, Geneva, 1958), Vol. 32, P/1789, p. 398.

Y6. A Study of the N_2O Molecule Using Electron Beams. G. J. Schulz, *Westinghouse Research Laboratories.*—Inelastic processes and negative ion formation by electron impact in N_2O are measured using the trapped-electron method[1] and conventional techniques, respectively. A large inelastic process is observed at 2.2 ev and is interpreted as the formation of vibrationally excited N_2O via the formation of a temporary negative ion state. Negative ions, O^-, are observed beginning at 0 ev with peaks of the negative ion current occurring at 0.7 and 2.2 ev. The latter peak is attributed to the formation of the previously mentioned temporary negative ion with subsequent decay into a stable O^- plus N_2 in various states of vibrational excitation. Measurements of the kinetic energy of the negative ions confirm this hypothesis.

[1] G. J. Schulz, Phys. Rev. 116, 1141 (1959).

Y7. Dissociation by Slow Electrons of CO Adsorbed to Molybdenum. George E. Moore, *Bell Telephone Laboratories.*—When a monomolecular layer or less of CO is adsorbed to Mo, an incoming beam of slow electrons dissociates the CO to give O^+ ions as the only product leaving the system. Measurement of the O^+ ions in a mass spectrometer permits quantitative description of the process. The threshold for emission of O^+ from adsorbed CO is apparently several volts less than the threshold for O^+ liberation from gaseous CO molecules. The amount of dissociation is directly proportional to the incoming electron current. Possibly of greater interest, the electron beam can be used as a probe which perturbs the adsorbed system only slightly and enables one to measure rather directly the kinetics of adsorption-desorption processes for this system and the competition of various other molecular species for the available adsorption sites. The method is probably suitable for the study of other adsorption systems.

Y8. Recombination Study of Atomic Oxygen by Paramagnetic Resonance Absorption and Isothermal Calorimetric Detection.* S. A. Marshall, M. Steinberg, and D. S. Hacker, *Armour Research Foundation.*—Catalytic surface recombination of atomic oxygen under flow conditions has been studied by paramagnetic resonance absorption and by an isothermal platinum wire detector. Relative oxygen atom concentration obtained by the platinum wire detector is found to be in fair agreement with concentrations obtained by paramagnetic resonance absorption. Recombination of oxygen atoms on a quartz surface is found to follow first-order kinetics with a surface recombination efficiency of 3.9×10^{-5}. Platinum filaments held at 200°C and 850°C and calibrated against the paramagnetic resonance absorption of oxygen atoms are found to have mean recombination efficiencies of 0.005 and 0.05, respectively. Atom recombination obtained by the flow method also indicates formation of ozone according to the scheme

$$O+O_2+O_2 \rightarrow O_3+O_2,$$

which is first-order in oxygen atoms with a rate constant of 2.5×10^{14} cc^2 mole^{-2} sec^{-1}.

* This work sponsored by the National Aeronautics and Space Administration and by the Armour Research Foundation.

Y9. Thermal Decomposition of Alpha Lead Azide.* Otto H. Hill, *Convair Division of General Dynamics Corporation* (introduced by J. A. Staples, III).—Thermal decomposition of >200-mesh, pure alpha lead azide shows an acceleratory period extending over the initial 7% sample decomposition.

The activation energy associated with the exponential formulation of these kinetics is 41.3 kcal/mole. The log rate vs log time data exhibit slopes of 7.1 ± 0.2 with unresolvable temperature dependence. After the method of Thomas and Tompkins, the acceleratory period can be described in terms of the formation and growth of stable, triple *F*-center nuclei. The rate determining process for nulceus formation, corresponding to the ejection of an electron from the azide ion into the conduction band, exhibits an activation energy of 51 ± 2 kcal/mole. Nucleus growth by the thermal excitation of an azide electron into a vacant level of an adjacent metal atom yields an activation energy of 36 ± 1 kcal/mole. Photographic evidence of the formation and growth of compact, discrete, metallic nuclei was obtained.

* Work performed at Defense Research Laboratory, University of Texas, under contract with ERDL, Fort Belvoir, Virginia.

Y10. Hydromagnet, a Self-Generating Liquid Conductor Electromagnet. HENRY H. KOLM, *Lincoln Laboratory,* MIT.*—The intensity of continuous man-made magnetic fields is limited to 100 kgauss by present economic restrictions and to about 250 kgauss by the mechanical strength of copper. Stronger alloys have survived short pulses up to 750 kgauss, but their use for transient or continuous operation would entail expenditures presently considered absurd. Liquid conductors, notably Ag, Na, and NaK, have comparable resistivity but offer the possibility of vastly superior heat removal. This permits the operation of reasonably small solenoids at unprecedented specific power dissipation in which magnetic forces are contained hydrostatically by a confining envelope at no internal loss of conductor volume. A particularly advantageous possibility is that of generating current within the solenoid itself by forcing the liquid conductor radially inward through the space between two coaxial cylinders placed in an axial magnetic field. The tangential current thus generated within the flowing conductor adds to the initial applied field so that the device in effect represents a self-exciting, internally short-circuited homopolar generator. A "hydromagnet" of this type can be operated continuously or on a transient basis, thus permitting the use of stored energy in its most economical form, a chemical explosive.

* Operated with support from the U. S. Army, Navy, and Air Force.

Y11. On the Theory of the Hydromagnet.* OSMAN K. MAWARDI, *MIT.*—A study of the operating characteristics of the hydromagnet discussed by Kolm[1] is presented in detail. It is shown that, for continuous operation, the amplification of the magnetic field inside the hydromagnet is almost independent of the hydrodynamic Reynolds number but depends strongly on the magnetic Reynolds number and on the ratio of the inner to the outer radius of the hydromagnet. The analysis treats the cases of magnetic Reynolds number less than and greater than unity. It is found that for small magnetic Reynolds numbers the amplification is a quadratic function of the ratio of the radii of the hydromagnet and that the total dissipation in the magnet depends on the square of the amplification and on the cube of the hydrodynamic Reynolds number.

* Supported in part by the Geophysics Research Directorate, U. S. Air Force Cambridge Research Center, Air Research and Development Command.

[1] H. H. Kolm, preceding abstract.

Y12. Polarizabilities of The Alkalis.* A. SALOP, E. POLLACK, AND B. BEDERSON, *New York University,* AND J. EISINGER, *Bell Telephone Laboratories.*—A novel atomic beam method is being used to measure the polarizabilities (α) of the alkalis. Congruent, inhomogeneous E and H fields are established in the same region of space by applying a potential difference to pole faces of high permeability which are insulated from their magnet yoke. The magnetic and electric forces can be made to balance for particular magnetic substates for sufficiently narrow beams. When the balance condition is satisfied for a particular magnetic substate, $\alpha=\mu_{\text{eff}}H/E^2$, where μ_{eff} is the effective magnetic moment. The determination of α is independent of the atom velocity distribution and, because of the $E-H$ congruence, is also independent of the field gradients. H is measured to good precision by using convenient alkali zero moments. At present, absolute accuracy for the α's is limited by uncertainty in the determination of E, which is calculated from the known gap geometry. Preliminary measurements yield α's for K, Rb, and Cs as 37 ± 7, 40 ± 8, and $53\pm11\times10^{-24}$ cm^3, respectively. Errors for the relative values are about one-fourth of the above quoted errors. Work is in progress to normalize these results to the polarizability of H[1].

* Supported by the Office of Naval Research.

FRIDAY AFTERNOON AT 1:30

McConnell Engineering Building 304

(R. W. GOULD presiding)

Plasma Physics, VI

Z1. Slow Wave Propagation in a Cylindrically Confined Plasma. H. L. POSS, M. GLICKSMAN, AND W. A. CONRAD, *RCA Laboratories.*—Slow wave propagation along the plasma column of a cesium discharge tube for the case of zero magnetic field has been studied using an experimental arrangement similar to that of Trivelpiece and Gould.[1] Wavelength as a function of frequency was measured over the range 250 to 4000 Mc for discharge currents up to 2 amp. The section of the tube in which the plasma was produced was 25 cm long and 0.7 cm in diameter. A signal generator was connected to the anode at one end of the tube, and the resulting slow wave fields were detected using a movable probe inserted into a slotted outer conductor which enclosed the plasma column. Reciprocity measurements made by interchanging the detector and generator indicate that the effects of drift velocity and axial density gradients are small. For low discharge currents, plots of frequency vs βa ($\beta=2\pi/\text{wavelength}$, $a=\text{radius of plasma column}$) are in accord with theory.[1] At higher discharge currents, breaks in the curves appear and the wave patterns become more complex.

[1] A. W. Trivelpiece and R. W. Gould, J. Appl. Phys. **30**, 1784 (1959).

Z2. Regular Oscillations in a Toroidal Discharge. D. J. LEES, M. G. RUSBRIDGE, P. A. H. SAUNDERS, AND E. A. WITALIS, *A.E.R.E., Harwell.*—Regular oscillations of electric and magnetic fields have been observed in hydrogen discharges in a 12-in. bore torus of 4:1 aspect ratio for currents below about 8 ka and applied fields below 80 gauss, and gas pressures in the range 0.4–2.0 μ. These oscillations are propagated as traveling waves with frequencies in the range 2–15 kc/sec and

wavelength about 45 cm. Similar oscillations are observed in discharges in argon with frequencies lower by a factor of about 4. The electric field oscillations, observed with an electrostatic probe, consist of regularly spaced short pulses of up to 10-v/cm amplitude, correlated with the magnetic field oscillations, with random fluctuations of frequencies up to at least 1 Mc/sec superimposed. During the pulse the radial component of plasma velocity, given by $E\Delta B/|B|^2$, is directed outwards. It is suggested that the structure of the wave is similar to that studied by Sawyer, Scott, and Stratton[1]; the electric field is developed across the notch in the current channel observed by them, which would then be a region of turbulent outward motion of the plasma. The relevance of these observations to the high-current containment problem will be discussed.

[1] G. A. Sawyer, P. L. Scott, and T. F. Stratton, Phys. Fluids 2, 47 (1959).

Z3. Radial Normal Modes of a Cylindrical Plasma.* RICHARD L. MOORE, *Richard L. Moore, Consultant.*—For a constant external field, these modes have been obtained from a plasma vector wave equation by the boundary condition that the maximum velocity occurs at the surface. A Gaussian distribution is found for the radial density, and a close relation between the fundamental resonant frequency and the usual plasma frequency will be shown. Agreement is obtained with the experimental results as noted by Hershberger and Moore[1] that the Bessel functions $J_{n-1}(\beta r)$ are zero at successive resonances. n is an integer and c is the speed of sound for the plasma or electron gas. H is either H_z or H_θ external to the plasma, M is the linear density of plasma, A_n is a constant. (m^2-1) is a positive number such that $J_{n-1}(\beta r)$ is zero. β is $[H/2c][(m^2-1)\gamma/M]^{\frac{1}{2}}$. The radial velocity is found to be $A_n(\beta r)^n J_n(\beta r)\sin(tmc\beta/(m^2-1)^{\frac{1}{2}})$.

* Work supported by Norair Division, Northrop Corporation.
[1] W. D. Hershberger and R. L. Moore, J. Appl. Phys. (to be published).

Z4. Plasma Oscillations in an Applied Electric Field. M. MITCHNER, *Lockheed Aircraft Corporation.*—The effect of a small electric field applied to a plasma is to produce an electric current which is approximately in a steady state for times sufficiently small. The dispersion relation for plasma oscillations under these circumstances is derived, corresponding to a generalization of the equation considered by Landau. For small fields and times the current will, of course, be stable. However, it is shown that, even in the absence of ion motion, the introduction of the electric field is to produce a tendency towards instability.

Z5. Experimental Two-Beam Excitation of Electron Oscillations in a Plasma without Sheaths. M. J. KOFOID AND S. E. SOBOTTKA, *Boeing Scientific Research Laboratories.*—Coherent standing waves of longitudinal electron oscillations have been excited in a plasma by two independent oppositely directed electron beams. Identical beams of 65-ev electrons entered the plasma through 1.0-mm diam apertures in plane electrodes which were at plasma potential, or slightly positive. The apertures faced each other across 2.0 cm of plasma whose electron density corresponded to a Langmuir frequency of about 550 Mc. The axes of the two beams coincided. The tests were made in argon at 14-μ pressure. Detection was by means of a 0.20-mm diameter movable probe located 2 mm from the visible edge of the interpenetrating beams. Strong standing waves, with either one or two loops between beam electrodes, were found at 550 Mc when (and only when) both beams were present. This experiment provides an example of the observation of what appears to be a nonconvective instability.[1]

[1] P. A. Sturrock, Phys. Rev. 112, 1488 (1958).

Z6. Interaction of a Bounded Microwave Field with a Cold Plasma in a Magnetic Field. S. J. BUCHSBAUM, *Bell Telephone Laboratories,* LYMAN MOWER,* *University of New Hampshire,* AND SANBORN C. BROWN,* *MIT.*—A cylindrical plasma column is introduced coaxially into a cylindrical microwave cavity which resonates in the TE_{011} mode. An axial, static magnetic field is present. It will be shown that the interaction between the plasma column and the microwave field of the TE_{011} mode can be described, in almost all respects, by the propagation characteristics of the extraordinary plane wave (electric field and the direction of propagation both at right angles to the static magnetic field) in an infinite uniform plasma. Results of exact calculations which support this view will be presented.

* Supported in part by the U. S. Army (Signal Corps), the U. S. Air Force (Office of Scientific Research, Air Research and Development Command), and the U. S. Navy (Office of Naval Research); and in part by the U. S. Atomic Energy Commission.

Z7. Propagation of Radiation along a Plasma-Dielectric Interface. JULIUS KANE, *Dorne & Margolin, Inc.*—It has been shown[1] by the author that radiation of an antenna in the vicinity of a reactive surface will launch large amounts of power into a surface wave field and comparatively small power into the cylindrical field. It is the purpose of this report to show that a plasma-dielectric interface will behave as a reactive plane which supports surface waves if the radiation frequency of the antenna is below the plasma frequency. The equivalent reactance of the interface and the amplitude of the surface wave are computed as a function of the physical parameters. These ideas can be applied to the problem of the radiation of a telemetry antenna on a re-entrant nose cone.

[1] Julius Kane in *Transactions of the Professional Group on Antennas and Propagation* (PGAP) (Institute of Radio Engineers, New York, September, 1960) (to be published).

Z8. Electromagnetic Waves in a Magnetized Plasma. I. P. SHKAROFSKY AND T. W. JOHNSTON, *RCA Victor Research Laboratories.*—An equation for the refractive index of an electromagnetic wave propagating in a plasma at an angle with respect to an applied dc magnetic field has been generalized for arbitrary variations of the collision frequency with electron velocity. This generalized equation follows from Astrom's analysis if one applies the integral equations for the conductivity matrix elements and one does not restrict the velocity variation of the collision frequency. The result can be manipulated to assume a form similar to the Appleton-Hartree equation, to which it becomes identical for constant collision frequency. There is an additional angular dependent term which differes from zero for the same reason that Tonks' theorem is violated for a plasma with a collision frequency varying with electron velocity. For the lossless case, stop and passbands for the various elementary waves are very conveniently represented by plotting $\omega_b\omega/(\omega_b^2+\omega_p^2)$ vs $\omega_p\omega/(\omega_b^2+\omega_p^2)$. Such a representation is extremely useful in obtaining the width of the frequency passbands for any given ratio of ω_b/ω_p and for including the effects of ions.

Z9. Microwave Measurements of Plasma Temperature.* G. BEKEFI, *MIT.*—The radiation temperature of the positive column of a glow discharge in helium and hydrogen was measured as a function of the current, the axial electric field E, and the gas pressure p. The measurements were made for values of E/p from 1 v to 50 v cm^{-1} mm Hg^{-1} and for currents between 10^{-3} and 1 amp. The results are compared with calculations of the temperature of the positive column. The effect of an axial dc magnetic field on the temperature was studied for fields up to 2500 gauss. Measurements show that the anomalous increase of E at certain critical magnetic fields, which has been observered recently, is accompanied by an increase of the plasma temperature. The microwave noise radiation was detected at a frequency of 3000 Mc. The plasma was illuminated by a blackbody source of known, variable temperature. The blackbody temperature was adjusted until the noise power

received became independent of the presence of the unknown plasma. At this point, the temperature of the two radiators is the same, and the measurements are independent of the plasma emissivity.

* Supported in part by the U. S. Army (Signal Corps), the U. S. Air Force (Office of Scientific Research, Air Research and Development Command), and the U. S. Navy (Office of Naval Research); and in part by the U. S. Atomic Energy Commission.

Z10. Line Profiles of Cyclotron Radiation.* J. L. HIRSHFIELD, *MIT*.—For a plasma in thermal equilibrium, the emission is obtained from the absorption via Kirchhoff's radiation law. For a transparent ($\omega_p^2/\omega_b\nu_c \ll 1$), low-temperature [$(kT/mc^2)^{\frac{1}{2}} \ll \nu_c/\omega_b$] plasma, in which the damping of electromagnetic waves is governed chiefly by collisions, we have previously shown that the line shape is Lorentzian for a constant collision frequency.[1] The same result has been obtained from single-particle considerations.[2] Experimental comparisons of line profiles with theory, covering a range of more than four half-widths, are presented. At lower collision frequencies and/or higher electron temperatures, when the electron's thermal motion can influence the wave damping, the absorption coefficient, as deduced from Sitenko and Stepanov's[3] permittivity tensor, yields a Voigt profile for the emission, provided that $\omega_p^2/\omega_b\nu_c \ll 1$. This also agrees with what one would infer from single-particle considerations. Experimentally observed line profiles at low-collision frequencies will be discussed.

* Supported in part by the U. S. Army (Signal Corps), the U. S. Air Force (Office of Scientific Research, Air Research and Development Command), and the U. S. Navy (Office of Naval Research); and in part by the U. S. Atomic Energy Commission.

[1] J. L. Hirshfield and G. Bekefi, Bull. Am. Phys. Soc. Ser. II, **5**, 124 (1960).
[2] L. Oster, Phys. Rev. **116**, 474 (1959).
[3] A. G. Sitenko and K. N. Stepanov, Soviet Phys.-JETP **4**, 512 (1957).

Z11. Receiving-Antenna Influence on Cyclotron Radiation Measurements.* S. GRUBER,† *MIT* (introduced by Sanborn C. Brown).—The measured shape of a pressure-broadened line is modified by the length of time spent by an average electron within the region of observation. This effect becomes important at low pressures when the probability of an electron making a collision within the region of observation is small. The line shape as measured is determined by the length of time spent by an electron in the observation region and by the receiving-antenna pattern at the plasma. A relationship is derived for the power received as a function of frequency in terms of the probability distribution of collisions, the electron velocity distribution along the dc magnetic field, and the antenna pattern. An antenna pattern producing a one-to-one correspondence between the measured power spectrum and the electron velocity distribution is given. Experimental results obtained at a frequency of 8.2 kMc with an open waveguide used as the receiving antenna illustrate the effect.

* Supported in part by the U. S. Army (Signal Corps), the U. S. Air Force (Office of Scientific Research, Air Research and Development Command), and the U. S. Navy (Office of Naval Research); and in part by the U. S. Atomic Energy Commission.

Z12. Measurements of Oscillation Frequency and Saturation Emission Currents in Cesium Diodes. MILTON GOTTLIEB AND R. J. ZOLLWEG, *Westinghouse Research Laboratories*.—The factors influencing the oscillations sometimes present during the operation of a cesium plasma thermionic cell have been investigated. They are observed with a tungsten cathode, nickel anode cell under the conditions of low cesium pressure ($\sim 10^{-3}$ mm Hg) and high cathode temperature ($\sim$2000°C); and high cesium pressure ($\sim$0.5 mm Hg) and low cathode temperature ($\sim$1300°C). For constant cell potential, the period of the oscillations was found to be proportional to the cathode-anode spacing in the range from 1 mm to 1 cm. The effect of cell current and applied cell voltage on the period and amplitude was found to be in agreement with a model of plasma oscillations discussed by Waymouth.[1] Rough agreement is also obtained for the period variation with the ion density, as calculated from the cesium pressure and cathode temperature. The disappearance of the oscillations has been used to measure the saturation emission current as has previously been done with fluorescent lamp tubes.[1] The saturation emission currents measured by this method are compared to the extrapolated values of Langmuir.

[1] J. F. Waymouth, Sylvania Tech. **13**, 2 (1960).

Z13. Ion Waves in a Hot Plasma. BURTON D. FRIED AND ROY W. GOULD, *Space Technology Laboratories, Los Angeles*.—The linear, longitudinal waves in a hot plasma include, besides the familiar electron plasma oscillations with frequency $\omega \approx \omega_p = (4\pi ne^2/m)^{\frac{1}{2}}$, also ion plasma oscillations (*ipo*) with $\omega \approx \omega_p(m/M)^{\frac{1}{2}}$. The properties of these *ipo* are explored using a Vlasov equation description of the plasma. The roots of the dispersion equation are found as functions of wave number k, and their locii in the complex ω/k plane are shown. For equal temperatures $T_e = T_i$, there exists a discrete sequence of *ipo* but all are so strongly damped ($d = \mathrm{Im}\,\omega/\mathrm{Re}\,\omega \gtrsim 0.5$) as to make detection unlikely. The ratio d can be decreased by increasing T_e/T_i or by producing a current flow. The latter can even reverse the sign Imω, giving growing waves (the familiar "two stream instability," which is thus seen to be an unstable *ipo*); the current required is smaller the larger the value of T_e/T_i and approaches zero with T_i as shown by Bernstein et al.[1] For large T_e/T_i and small k the *ipo* behave like acoustic waves ($\omega \propto k$) notwithstanding the use of a formalism sometimes designated as "collisionless."

[1] I. B. Bernstein, E. A. Frieman, R. M. Kulsrud, and M. N. Rosenbluth, Phys. Fluids **3**, 136 (1960).

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Proceedings of the American Physical Society

Minutes of the 1960 Annual, Southwestern, and March Meetings

WE will combine the Minutes of the first three meetings of 1960 in order to bring out the contrasts among them.

The registration at the Annual Meeting (New York, January 27–30) was 3865, that at the Southwestern Meeting (Houston, March 4–5) was 269, and that at the March meeting (Detroit, March 21–24) was 1180. These figures made the January meeting the biggest in our history, the Southwestern meeting one of the pleasantest, and the Detroit meeting the second biggest of the "March" sequence and largest of those held west of the Alleghenies (the experience of several years has shown that the crossing of this not very formidable range of mountains always makes a significant difference in the attendance). Members of the American Association of Physics Teachers may cavil that it was the participation of their Society that made the Annual Meeting so populous: the records show that 692 people registered as members of AAPT but of these 439 were members of our Society also. Wherever the registrants came from, they were too many for comfort.

There is another way of measuring a meeting: by counting the contributed (ten-minute) papers. Of these there were 419 at New York, 62 at Houston, and 318 at Detroit. The first was the largest number ever presented at a New York meeting, though inferior to that of at least one Washington meeting; the second and the third set no records, though the Detroit meeting came so near to the total of the record March meeting (Cambridge in 1959) that it may well be considered as having tied its predecessor. Incidentally this shows that when the March meeting goes to the Midwest the number of papers does not fall off in nearly the same proportion as the number of registrants. Apparently people will travel farther to give a paper than to hear one.

The invited papers at Detroit were those bespoken by our Divisions of High-Polymer Physics, Solid-State Physics, and Chemical Physics (here listed in the order of their founding). The one invited paper at the March meeting which is to be regarded as a feature of the Society is the Oliver E. Buckley lecture, this year (the first after the lamented death of Oliver Buckley) given by Benjamin Lax. Since the invited papers at the March meeting are so restricted in their fields, we tend to stress nuclear and theoretical physics at the Annual Meetings, though usually—and this year in particular—there are symposia of the Divisions of Electron Physics, Solid-State Physics, and Fluid Dynamics. At the Southwestern meetings we strive for a wide spectrum of subjects combined with a special emphasis on the fields of research cultivated in the Southwest.

The banquets at the three meetings mustered 430 at New York, 142 at Houston, and 192 at Detroit. Thus George Kistiakowsky at New York appears to have carried off the palm, with J. H. Hollomon and R. A. Sawyer lagging considerably behind him at Detroit while W. V. Houston and R. W. G. Wyckoff ran third at Houston. However, there is ample consolation for the last-named in the figures of *relative* attendance. Here Messrs. Houston and Wyckoff did extraordinarily well by attracting more than half of the registrants, while Messrs. Hollomon and Sawyer drew a regrettable 15% and Mr. Kistiakowsky with his significant and timely speech a miserable 12%. The people for whom no consolation is to be found are the officers of the Society, who still fail pitiably to induce a respectable proportion of the registrants (elsewhere than in the Southwest) to do their duty to the Society and to its distinguished speakers by attending the banquets. It may be thought that the attendance is an inverse measure of the quality and accessibility of public restaurants, but the functional relation must be far from smooth, as it is impossible to believe that in this respect Detroit comes so close to New York and is so far ahead of Houston.

The weather at Detroit was icy and snowy. The weather at Houston was chilly to Texans, delectable to Northerners. The Secretary does not remember what the outdoor weather was at New York, but the indoor weather was distinctly stuffy, the crowds overtaxing the ventilation. Returning momentarily to the Houston meeting; at least five of the invited speakers failed to appear, because their planes were grounded in the Northeast. Their absence gave to the meeting an unusual and agreeable sense of limitless time, and the strict rules of the Society for limiting the lengths of invited papers were conveniently forgotten. Nevertheless, the absences were regrettable. People who fly to our meetings should start early enough so that if the planes are grounded they can reach the meeting place by rail. The trains to Houston were on time.

The heroes of these meetings were R. V. Adams, Chairman of the Local Committee at Detroit; T. W. Bonner, Chairman of the Local Committee at Houston; their numerous aides; and Emily Wolf and the rest of the staff of the American Institute of Physics which managed the huge affair at New York. At Detroit we had to pay rent for some of the (excellent) halls that we used, but we paid less

for some of them than is customarily demanded, and for these welcome concessions we thank the Engineering Society of Detroit, the University of Michigan through D. M. Dennison, and the Wayne State University through its President, Clarence Hilberry. Special thanks are due Wayne State University, for the facilities that it gave us at Detroit, and the Rice Institute for the facilities that it gave us at Houston; and very special and general thanks to all of the Local Committees mentioned above.

The only one of these meetings at which the Council elected candidates to Fellowship and to Membership was the one at New York. The list of those elected is appended.

Elected to Fellowship on January 27, 1960: Charles P. Bean, George Birnbaum, Richard C. Bradley, E. Richard Cohen, Donald C. Cronemeyer, Robert B. Day, B. C. Diven, Raymond L. Driscoll, Henry Ehrenreich, John C. Fisher B. C. Frazer, Thomas M. Hahn, Jr., Marshall C. Harrington, Edward W. Hart, Richard L. Henkel, Werner Kanzig, Edward Haskel Kerner, George B. Kistiakowsky, Bennett Kivel, Walter Kohn, F. Ralph Kotter, Martin D. Kruskal, Robert B. Leachman, Gordon W. McClure, Hans Meissner, John Wesley Mitchell, Ralph C. Mobley, Vincent E. Parker, Robert G. Parr, Murray Peshkin, James Alfred Phillips, David Pines, Robert L. Platzman, R. Ronald Rau, Fred Linden Ribe, Vance L. Sailor, George J. Schultz, John D. Seagrave, Sunil K. Sen, A. Melvin Skellett, Stephen J. Smith, Robert Stratton, Chan Mou Tchen, James L. Thomas, Moody C. Thompson, Alan M. Thorndike, Richard E. Trees, Joseph Weneser, John L. Yarnell, and Hubert P. Yockey.

Elected to Membership on January 27, 1960: Florin Abeles, William L. Adikes, *Alice Adler, H. Arthur Aghajanian, *James R. Albers, Shlomo Alexander, *Cynthia Alff, *Starling K. Alley, Gilbert Amat, Frank Anderson, *Norig G. Asbed, *Neil Ashby, *Henry Atlas, Vernon H. Ayre, Gilbert S. Bahn, Don A. Baker, Orville R. Baker, *David E. Baldwin, *Bhaskar B. Baliga, D. Boyd Barker, *Peter D. Barnes, *David F. Bartlett, Pierre Baruch, David R. Bates, Walter Bauer, Henry Berger, Gunnar B. Bergman, *Arnold Berkowitz, *Rene R. Bertrand, Frederick A. Bettelheim, Jyotindra Bhatt, *Ashor K. Bhattacharya *John Blair, Normn A. Blum, *David L. Book, S. John Brient *Daniel M. Brown, Gerald V. Brown, Marshall Bruce, *Robert A. Buchanan, Dimitri S. Bugnolo, Edward A. Burke, *Alan Burkow, Joseph Burlock, Charles Burmeister, David L. Bushnell, Don H. Byers, *Patrick T. Cahill, *Robert P. Caren, Edward F. Casassa, John F. Cassidy, William S. Chaney, Melvin L. Charters, *Yok Chen, *Robert J. L. Chimenti, Robert S. Christie, *James C. Clapp, George L. Clark, *Paul C. Claspy, Daniel L. Coleburn, John J. Condon, *Joseph H. Condon, *Hall L. Crannell, *Terry Tom Crow, B. Bryan Culwick, *Jerry H. Current, Edward M. DaSilva, Jesús Davila-Aponte, Walter F. Davison, Felix G. deForest, *Frank P. Del Greco, *George F. Dell, Jr., Robert E. DeLozier, *Alan W. DeSilva, *Delbert W. Devins, Richard D. Dick, *T. J. Diesel, *Reinhold E. Drews, Bernard E. Drimmer, Gerald Dvoek, Robert A. Dudley, *Vernon J. Ehlers, Frederick L. Ek, Charles Elbaum, *Stuart M. Ellerstein, *Roy M. Emrick, William B. Ericson, Bruce J. Faraday, Anthony J. Favale, Robert L. Ferguson, *Douglas K. Finnemore, *George P. Fisher, *David H. Fishman, *Willis H. Flygare, Edward M. Foley, *Paul Forman, Harold K. Forsen, *Jack Freed, *Louie A. Galloway, III, Carla Maria Garelli, J. B. Garg, Raymond L. Gause, David B. Geselowitz, Darrell J. Gillespie, Thomas J. Gilley, *Frederic M. Glaser, Klaus Goebel, Adolf Goetzberger, Sister Mary Grandfield, David Morris Grant, Alfred R. Gray, Claude G. Grenier, David D. Grewe, Robert L. Griffith, *David E. Groce, George L. Gross, Françoise Gurérin, *Zaven G. T. Guiragossian, *Joseph H. Hadley, Jr., Lawrence M. Hagen, W. Hanle, H. B. Hardy, Jr., *David R. Harrington, *Gale I. Harris, William J. Harris, Samuel R. Hawkins, Max A. Heaslet, Harry L. Heaslet, Harry L. Henneke, Gabriel F. Herrmann, *Merrill M. Hessel, *Nguyen C. Hien, Terrell L. Hill, Fred A. Hinchey, Stuart A. Hoenig, *Pierre C. Hohenberg, William S. Holmes, Edward T. Hooper, *David J. Hopp, Andrzej Z. Hrynkiewicz, Kurt Hubner, Torben Huus, Monte L. Hyder, John H. Ingold, Masafumi Inoki, Leslie L. Isaacs, Don M. Jackson, Jr., Albert J. Jaske, Jim H. Johnson, Joseph E. Johnson, Detlef G. Kamke, *Amnon Katz, *C. William Kern, *Chul Mo Kim, Wayne R. Knight, *Gundolf H. Kohlmaier, *Daniel D. Konowalow, *Wade M. Kornegay, *Richard D. Koshel, *Ralf H. Koslow, *Stephan J. Kreiger, Pierre Lafore, *Ronald A. Laing, *Murphy J. Landry, Edwin Langberg, Melvin T. Lavik, Edward Lax, Conrad J. Lennen, Richard M. Lessler, *Robert T. Lewis, John C. Light, Edward M. Little, *Liu Liu, *Samuel Hsi-peh Liu, *James H. Loehlin, Paul J. Long, *Arthur E. Lord, Jr., James Lowe, Kilburn MacMurraugh, Arthur G. Maki, Jr., *Demetrius J. Margaziotis, *Edward P. Marram, Donald R. Mason, *Shaikh Moizul Matin, Sheldon L. Matlow, William H. Mermagen, *Marshall F. Merriam, *Alvin A. Milgram, George Mohr, *Aram Mooradian, Emmett B. Moore, Jr., *H. Warren Moos, *Dornis C. Morin, Jr., *Richard C. Morrison, *Raymond D. Mountain, Colette Movchet, *Kalinath Mukherjee, *Murray Muraskin, Laurits T. Muus, Henry R. Myers, R. Michael McClintock, M. R. Coulter McDowell, *James B. McGuire, *John McKeen McKinley, William L. McLaughlin, R. F. McMurray, *Robert L. McPherron, Shigeru Nakano, Louis Neel, William F. Nelson, David R. Nethaway, Norris A. Nickols, Kazuhiko Nishijima, Alexander J. Noreika, *Melvin E. L. Oakes, *Terry F. O'Dwyer, Shimon Ofer, Albert S. Ogden, Guy F. Origlio, Robert J. Orsino, Robert J. Patton, Joseph J. Pello, John L. Peters, John I. Petz, *Waldemar A. Pieczonka, Paul Pietrokowsky, *James M. Piowaty, *Victor L. Pollak, *Gene J. Pontrelli, Earl C. Popp, *W. Maurice Pritchard, *Charles W. Putt, Hans J. Queisser, *Surendra A. Raje, Joseph L. Raymond, William W. Raymond, John A. Rayne, *Jacques B. J. Read, *Robert D. Reed, Richard P. Reed, *William A. Reed, Karl Reinitz, Darrell H. Reneker, Jacob Riseman, C. Sheldon Roberts, Jean-Michel Rocard, Edward Rolfe, Herbert R. Rosner, *Joseph H. Rosolowski, Donald C. Royal, *Edmund W. Rusche, Jr., Daniel G. Sanders, Lawrence J. Schaad, John J. Scholz, *Alton K. Schultz, *Jonas Schultz, *Todd M. Schuster, *Don Secrest, *Gerard Senecal, Irwin Share, *Mark Sharnoff, *Yitzhak Y. Sharon, Toshikazu Shibata, George A. Shirn, Anatol J. Shneiderov, *Jack C. Siddoway, Everett F. Sieckmann, Leonard Siegel, Hadley J. Smith, *Lawrence H. Smith, Ronald F. Soohoo, Gokaran N. Srivastave, John A. Stamper, Paul Stephas, Charles L. Stephens, Jr., Raul A. Stern, Daniel E. Stogryn, James Strickland, V. Robert Stull, Satoru Sugano, John O. Sullivan, *Michael J. Tannenbaum, James M. Tanner, Charles L. Tekl, Charles W. Terrell, *Douglas R. Thayer, Philip C. Thayer, David G. Thomas, David B. Thomson, Roger A. Tomboulian, *Walter C. Tripp, Yih-O Tu, Donald L. Turcotte, Lubomir J. Urbanek, *Worth E. Vaughan, Peter H. Verdick, *Frank N. von Hippel, Peter Vrahiotes, Clarence M. Wagener, Earl V. Wagoner, Jr., *Walter E. Ware, Yasushi Watanabe, Edgar Watts, Stewart Way, Helmut Weik, Jacob Weinard, *Richard W. West, Theodore R. Whyte, Wolfgang Wiese, *Robert B. Willmann, David H. Wing, William R. Wisseman, Helmut Wolf, Richard R. Woollett, Fumio Yagi, Masaru Yamano, Michael M. Yanase, Bernard Zendle, *Jonas S. Zmuidzinas, and *Harry S. Zwibel.

* Student.

Errata Pertaining to Abstracts A11, B7, DA6, E3, I4, OA1, S10, U7, and Y6 of the 1960 Annual Meeting in New York

(Series II, Vol. 5, No. 1)

A11 by Richard Schlegel. In the first line under the displayed formula, instead of "B approaches the limit $2u$" read "P approaches the limit $2u$."

B7 by J. H. Hamilton and B. G. Pettersson. In line 2, instead of "J. H. Hamilton* and B. G. Pettersson" read "J. H. Hamilton,* B. G. Pettersson, and J. Thun." Fifth line from end of text, instead of "Only in the allowed Na^{23} decay has an anisotropy been reported[2] (-0.27%)" read "Only in the allowed F^{20} and Na^{23} decays have anisotropies been reported.[2]" Change footnote 2 to read "[2]F. Boehm, V. Soergel, and B. Stech, Phys. Rev. Letters 1, 77 (1958); R. M. Steffen, Phys. Rev. Letters 3, 277 (1959)."

DA6 by Douglas Miller and Russell K. Hobbie. In line 10, instead of "1.9×10^{5}" read "2.9×10^{5}."

E3 by P. D. Miller, J. H. Gibbons, and R. L. Macklin. In the next to the last line, instead of "proportional to $E^{+\frac{1}{2}}$" read "proportional to $E^{-\frac{1}{2}}$." In the last line, instead of "$d\sigma/dE=0$ at 3 kev" read "$d\sigma/dE=0$ at 13 kev."

I4 by A. W. Sáenz and S. Podgor. The last sentence should read "This and similar results indicate that measurements of r for $f_0=f_N=0$, combined with a moderately accurate knowledge of Γ/E_0 and Γ_γ/Γ, determine J for a number of resonances of the kind specified above having sufficiently large Γ."

OA1 by S. A. Moszkowski. In the by-line, instead of "University of California, Berkeley" read "University of California, Los Angeles."

S10 by S. J. Pickart. In line 12, instead of "the spin sign alternating around the rhombohedral axis" read "the spin sign alternating along the rhombohedral axis."

U7 by H. M. Schwartz. In line 14, instead of "It involves the use of $\langle H^2\rangle$, which in the present case gives either a lower or an upper bound" read "It involves the use of $\langle H^2\rangle$, which in the present case gives either a lower bound or an upper bound *smaller than* $\langle H^2\rangle$."

Y6 by Melvin Cutler. In the title, instead of "Thermionic" read "Thermoelectric."

Errata Pertaining to Abstract F5, in the Minutes of the 12th Annual Gaseous Electronics Conference, Published in the 1960 Houston Bulletin

(Series II, Vol. 5, No. 2)

F5 by F. Kaufman and J. R. Kelso. In line 4, right-hand column, instead of "NL" read "NO." In line 7, right-hand column, instad of "Very pure O_2 produces less than 1% atomic oxygen for very small additions $\langle 0.01\%\rangle$ of N_2 molecule added" read "Very pure O_2 produces less than 1% atomic oxygen. For very small additions (0.01%) of N_2, this value rises at the rate of about 80 oxygen atoms produced for every N_2 molecule added."

Errata Pertaining to Abstracts D9, K5, L6, M1, OA9, and Z2 of the 1960 Detroit Meeting

(Series II, Vol. 5, No. 3)

D9 by J. A. Pesch and L. J. Fiegel. In the fourth line from the end, instead of "$+(3\pm0.4)\times10^{-5}$ and $+(1.5\pm0.04)\times10^{-4}$" read "$+(3\pm0.4)\times10^{-5}$ g/cm^3 and $+(1.5\pm0.04)\times10^{-4}$ g/cm^3."

K5 by R. C. Frank, R. W. Lee, and D. E. Swets. In the fourth line from the end, instead of "in the higher range it is 5600 cal/g atom" read "in the higher range it is 6610 cal/g atom."

L6 by S. Krimm. In line 13, instead of "$\nu_a-1.394$" read "$\nu_a-1.349$."

M1 by F. A. Bovey. The author's name should read "Bovey" instead of "Boney."

OA9 by Jin-Ichi Takamura. In line 13, instead of "$a=157$ mm^{-2}" read "$a=1.57$ mm^{-2}."

Z2 by N. G. McCrum. In the title read "polyoxymethylene" instead of "polyoxynethylene."

Amendment to the By-Laws of The American Physical Society, Adopted by the Society at Its Business Meeting on January 27, 1960

Article VIII of the By-Laws now reads as follows:

These By-Laws may be amended or suspended only by recommendation of the Council followed by favorable action of the Society. The recommendation shall require the favorable votes of a majority, but not fewer than six, of the Councillors present at a Council meeting. The recommendation may be submitted to the members of the Society present at a Business Meeting, and adoption shall require the affirmative votes of two-thirds of the members present and voting. Alternatively the Council may at its discretion circulate to the membership-at-large, by mail, copies of a proposed amendment or amendments to the By-Laws together with a ballot-form; and the distribution, marking, returning and counting of the ballots shall be carried out in the manner prescribed for amending the Constitution, adoption of the amendment or amendments requiring the affirmative votes of not fewer than two-thirds of the members voting.

Amendment to the Constitution of the American Physical Society, to be Submitted to the Membership-at-Large During 1960

This Amendment affects Article VI, Section 1, of the Constitution of The American Physical Society.

In the text which follows, the words not in italics constitute the Section in question as it now stands, and the words in italics are those which will be added if the amendment is adopted.

The President, Vice-President, Secretary, Treasurer, Managing Editor, the three Past Presidents most recently retired from office, eight other members elected in the manner specified in Article VII, *two non-voting members to be chosen as described below*, and all Past Presidents first elected to the office of President before December 1932, shall constitute a Council which shall have general charge of the affairs of the Society. *At each Annual Meeting the Council shall elect one non-voting member, who shall serve from the end of that meeting to the end of the next Annual Meeting but one. All members of the Council must be Fellows of the Society.* The Local Secretary for the Pacific Coast, the Deputy Secretary and the Deputy Treasurer may attend meetings of the Council, but may not vote except that the Deputy Secretary and the Deputy Treasurer may vote in the absence of their respective principals.

Pertaining to the American Physical Society Prize Sponsored by Hughes Aircraft Company

By order of the Council, members of the Society are invited to propose candidates for the 1960 American Physical Society Prize sponsored by Hughes Aircraft Company, and this they may do by writing to Professor V. F. Weisskopf, Massachusetts Institute of Technology, Cambridge 39, Massachusetts, who is Chairman of the Committee appointed to nominate candidates. Eventual decision is made by the Council.

This prize is awarded "for an outstanding contribution or contributions to the science of physics, which shall have been published, in a single paper or in more than one paper, in a journal or journals of The American Physical Society or in a journal or journals of the American Institute of Physics. The contribution or contributions must have been made before the prizewinner reached his thirty-third birthday." The prize may not be divided between two or more recipients.

Second Announcement of the 1960 Thanksgiving Meeting at Chicago

The 1960 Thanksgiving meeting of the Society will be held on the Friday and Saturday after Thanksgiving, November 25 and 26. Again we shall have the pleasure of meeting in Chicago and in the buildings of the University of Chicago. Again also we shall have the pleasure of using as our official hotel the Hotel Windermere, 1642 East 56th Street, Chicago, Illinois, and its management will find rooms at other hotels of the neighborhood for those who apply to it after our own quota of its rooms is exhausted. There is a project for a session or sessions on the Mössbauer effect, proposed from Argonne National Laboratory. Deadline will be Friday, September 23, and abstracts are to be sent to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York.

Preliminary Announcement of the 1960 Winter Meeting in the West

The 1960 Winter Meeting in the West will be held in Berkeley on the campus of the University of California. The Department of Physics will be the host. The dates are Thursday, Friday, and Saturday, December 29, 30, and 31. Pursuant to new policies of the Council of the Society, the meetings will be preceded by a special topical conference on high-energy physics, in this instance devoted to strong coupling. This conference will be held on Tuesday, Wednesday, and Thursday, December 27, 28, and 29 and the papers will be announced in the usual bulletin. There will be an overlap on Thursday, with the papers of the topical conference serving as invited papers for the regular meeting. This is the pattern that proved so successful for the Conference on Nuclear Radii that took place at the corresponding meeting at Stanford in 1957.

The hotels for the meeting are the Claremont, the Durant, and the Shattuck, all in Berkeley. Reservations will also be accepted at the conveniently situated motels on University Avenue.

The present Local Secretary for the Pacific Coast will be on leave of absence. Abstracts and all other communications pertaining to the meeting should be addressed to his deputy, Professor E. L. Hahn of the University of California at Berkeley, and until further notice all communications to the Society such as would normally come from the Local Secretary will be signed by him.

1960 Gaseous Electronics Conference

The Thirteenth Annual Gaseous Electronics Conference will be held at Monterey, California, on October 12–14, 1960, under the sponsorship of the U. S. Naval Postgraduate School and that of the Division of Electron Physics of The American Physical Society. The scope of this conference embraces fundamental knowledge in the whole field of ionization and discharge in gases, not excluding plasma dynamics; but papers on specific devices will not be admitted.

Abstracts of contributed papers may be sent to N. L. Oleson, Conference Secretary, U. S. Naval Post graduate School, Monterey, California, and must reach him not later than August 24, 1960. Abstracts must conform to the same regulations as are imposed on those that are submitted for general meetings of the Society! As always, it is the prerogative of the management of the Conference to accept or decline contributed papers as it chooses. The Conference Committee will not accept a greater number of contributed papers than is compatible with its intent to keep the meeting within three days, to avoid simultaneous sessions, and to provide adequate time for presentation and discussion of the papers that are accepted.

1960 Annual Meeting of the Division of Plasma Physics

Our Division of Plasma Physics will convene at Gatlinburg, Tennessee, on November 2, 3, and 4. This will be its second annual meeting. Oak Ridge National Laboratory will act as host. An organized tour of the fusion experimental area of the Laboratory will be available on Saturday, November 5, for those who wish to take part. Further information must be sought from A. H. Snell, Oak Ridge National Laboratory, Oak Ridge, Tennessee. Abstracts of contributed papers are to be sent to Albert Simon at the same address, and must reach him not later than September 26. They must conform to the same regulations as are imposed on those that are submitted for general meetings of the Society!

1960 Annual Meeting of the Division of Fluid Dynamics

Our Division of Fluid Dynamics will convene at Baltimore, Maryland, on the campus of The Johns Hopkins University, on the three days preceding Thanksgiving: November 21, 22, 23. This meeting will be devoted to various aspects of the physics of fluids, including hydrodynamics, magneto-fluid dynamics, rarefied gas dynamics, turbulence and boundary layer phenomena, high-speed and high-temperature fluid flows, superfluidity, and several fluid dynamical aspects of oceanography and atmospheric physics. The object of the Division of Fluid Dynamics is the advancement and diffusion of knowledge of the physics of fluids with special emphasis on the dynamical aspects of liquid, plastic, and gaseous states under all conditions of density and temperature. Abstracts of contributed papers of not over 200 words, prepared in accordance with the rules printed in this Bulletin, should be sent in duplicate to the Secretary of the Division, Raymond J. Emrich, Department of Physics, Lehigh University, Bethlehem, Pennsylvania. Deadline date for receipt of abstracts is October 7, 1960.

Communication from the Treasurer

For the information of the members the Treasurer presents the following statements condensed from the report for the year 1959 of Conroy, Smith and Company, auditors, as presented to the Council at Washington on April 25, 1960.

SHIRLEY L. QUIMBY, *Treasurer*

OPERATING INCOME AND EXPENSES ALLOCABLE TO THE YEAR ENDING DECEMBER 31, 1959

Income:				
Membership dues			$228 494.12	
The Physical Review				
Income:				
Nonmember subscriptions	$140 398.50			
Published articles	176 787.05			
Sale of back numbers	9 305.05			
Member subscriptions	73 128.37	$399 618.97		
Expenses:				
Cost of production and distribution: 6948 pages to 7567 member and 3400 nonmember subscribers	$335 329.13			
Editorial office	58 612.42	$393 941.55	5 677.42	
Reviews of Modern Physics				
Income:				
Member and nonmember subscriptions	$ 52 306.70			
Published articles	27 425.03			
Sale of back numbers	6 658.45	$ 86 390.18		
Expenses:				
Cost of production and distribution: 1104 pages to 1466 member and 9619 nonmember subscribers	$ 71 231.58			
Editorial office	2 968.05	$ 73 993.63	$ 12 190.55	
Net receipts from dinners and registration fees			$ 4 128.90	
Interest on securities and savings accounts			7 825.30	
Gain on sale of securities			413.37	
Sale of *The Physical Review Cumulative Index*			527.74	
Buckley Physics Prize Award Trust			250.00	
Prize award—Hughes Aircraft Company (Contra)			2 500.00	
Miscellaneous			584.43	$265 489.68
Expenses:				
Office of the Secretary and Treasurer:				
Salaries		$ 17 731.69		
Taxes, insurance, retirement fund		961.85		
Travel expenses of officers		5 096.81		
General office expenses		4 329.92	$ 28 120.27	
American Institute of Physics—Collection of dues and subscriptions			23 353.92	
Physical Review Letters				
Income:				
Nonmember subscriptions	$ 19 189.30			
Published articles	33 669.63			
Sale of back numbers	66.13			
Member subscriptions	27 711.60	$ 80 636.66		
Expenses:				
Cost of production and distribution to 5349 member and 1792 nonmember subscribers	$ 66 565.71			
Editorial office	34 055.86	$100 621.57	$ 19 984.91	

Bulletin—Cost of printing and mailing	32 538.62		
Editorial mechanics—A.I.P.	4 496.70		
	37 035.32		
Deduct—Income from subscriptions	6 273.70	$ 30 761.62	
Cost of membership and reduced rate subscriptions in excess of amounts collected therefore:			
The Review of Scientific Instruments	$ 1 754.50		
The Journal of Chemical Physics	4 876.00		
Journal of Applied Physics	9 873.50		
The Physics of Fluids	1 023.50	$ 17 527.50	
Contribution to The Institution of Electrical Engineers		41 060.00	
Contribution for maintenance and support of The American Institute of Physics		24 272.96	
Prize award (Contra)		2 500.00	
Custodian fee		283.65	
Ballots and postage expense charges by the American Institute of Physics		1 568.89	$189 433.72
Net income from operations of 1959			$ 76 055.96

Balance Sheet as of December 31, 1959

Assets

Cash on deposit:			
Checking account		$154 617.32	
Custodian account		1 938.44	$156 555.76
Accounts receivable:			
American Institute of Physics		$ 22 961.04	
Hughes Aircraft Company		1 500.00	24 461.04
Investments—at cost:			
Bonds (Market value $254 414.33)		$266 910.78	
Stocks (Market value $142 464.75)		98 775.92	365 686.70
Deferred charges:			
Cost of membership and reduced rate subscriptions to various journals in excess of the amounts collected therefore		$ 14 105.00	
Payment to The Institution of Electrical Engineers for 1960 contribution and abstract subscriptions		13 468.35	
Sundry		477.46	28 050.81
			$574 754.31

Liabilities and Accumulated Income

Accounts payable			
The Institution of Electrical Engineers		$ 9 060.00	
Division of Chemical Physics		734.61	
Others—for payroll taxes and expenses		5 269.04	$ 15 063.65
Deferred credits:			
Membership dues—year 1960		$172 437.50	
Subscriptions received from members applicable to issues of journals to be published subsequent to December 31, 1959:			
The Physical Review	$54 615.94		
Physical Review Letters	22 020.12		
Physics Abstracts and Engineering Abstracts	7 802.45		
Bulletin	3 401.24	87 839.75	$260 277.25
Accumulated income at January 1, 1959		$223 357.45	
Add: Excess of income over expenses year ended December 31, 1959		76 055.96	299 413.41
			$574 754.31

MEETINGS AND DEADLINES THROUGH AUTUMN 1961

Place	*Meeting dates*	*Deadline date*
Montreal	June 15–17	Past
Chicago	November 25–26	September 23
Berkeley*	December 29–31	October 14
New York	February 1–4, 1961	November 11
Monterey*	March 20–22	January 13
Washington	April 24–27	undecided
Mexico City	June 22–24	undecided
Chicago	November 24–25	undecided
Los Angeles	end of December	undecided

Abstracts for the meetings marked with asterisks are to be sent to Professor E. L. Hahn, University of California, Berkeley 4, California, and must reach his office not later than the corresponding deadline date. Abstracts for the other meetings listed above are to be sent to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York, and must reach his office not later than the corresponding deadline date. Take note that abstracts mailed the day before deadline day often fail to arrive in time: the last postal delivery of the day usually comes to our office before 2 p.m. *Allow at least two days for abstracts sent by airmail from points east of the Mississippi, and longer for those sent from farther west.* Abstracts postmarked (at the point of dispatch) on deadline day are instantly rejected. No abstract postmarked (at the point of dispatch) on deadline day ever reaches the office on time, nor does any abstract postmarked at any point west of the Rockies on the day before deadline day. Some abstracts arrive with covering letters dated three or more days before the postmark; it may be a good idea for you to put your abstract into a United States mail box with your own hands. *The privilege of contributing papers to meetings of The American Physical Society is restricted to the members of the Society and to nonmembers whose papers are sponsored by members.*

DIVISIONAL MEETINGS AND TOPICAL CONFERENCES (see page 392)

Monterey	Gaseous Electronics	October 12–14	August 24
Gatlinburg	Plasma Physics	November 2–4	September 26
Baltimore	Fluid Dynamics	November 21–23	October 7

RULES AND INSTRUCTIONS FOR THE PREPARATION OF ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words or to its actual length in words, whichever is the greater; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten; *one must be an original*, the other may be an original or a carbon copy. *Carbon copies will not be accepted in lieu of originals:* they smear. *Abstracts must be double-spaced:* single-spaced manuscripts are too crowded to permit the editorial markings to be made with ease and clearness. *Each abstract must be confined to a single page:* if it is too long for a single page it is too long to be printed. If we receive an abstract typed on two pages, we print only its first page. *Write each abstract as a single paragraph:* the suppression of paragraphs costs time and labor to the editors. *Do not use very thin paper:* a sheet of very thin paper may cause extraordinary trouble when mixed with sheets of reasonable thickness. The American Institute of Physics will bless you if you type first the title of your abstract in lower-case with capitalized initials, then your name in capitals, then the name of your institution in lower-case underlined with capitalized initials. It is a pleasure to report that those who qualify for this blessing are increasing in number but are still quite a bit short of 100% of the total. Issues of the *Bulletin* are always appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line.

It has now become an expensive business to make any change in an abstract, even the smallest, after the abstract has gone to press. By order of our Council "A change in an abstract will be permitted only at the discretion of the Secretary or his deputy, and only if TEN DOLLARS is enclosed with the letter in which the change is requested." As heretofore, an abstract will not be withdrawn from proof unless the asker sends ten dollars with his request.

New Instructions

(*a*) *If it is wished that two abstracts be scheduled consecutively, write on the first "To be scheduled before abstract ..... by ....." and on the second "To be scheduled after abstract ..... by ....."*

(*b*) *If a member insists that his paper be scheduled for a particular day or not on a particular day, he will get his wish, but usually at the price of having his contribution included in a session to which it is irrelevant.*

(*c*) *The Secretary and his deputies have been empowered by the Council to count a footnote either as ten words or as its actual length in words, whichever is the greater length.*

(*d*) *In general, all instructions about an abstract should be typed at the bottom of the page that has the abstract on it,* never *in a covering letter. Covering letters get separated from abstracts!*

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The American Physical Society

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Memoranda

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